Scotland's Rural College

Managing faba bean to reduce the yield gap: A synthesis from the Legume Gap project

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ASSOCIATION OF APPLIED BIOLOGISTS

President: Professor Christine Foyer

Legumes Translated

ASSOCIATION OF APPLIED BIOLOGISTS
Cropping and the Environment Group

ÉCOLE SUPÉRIEURE D'AGRICULTURES
Angers Loire

Legume Science and Practice 2

A three day virtual conference

on 1st-3rd September 2021

FINAL PROGRAMME

Association of Applied Biologists, Warwick Enterprise Park, Wellesbourne, Warwick CV35 9EF, UK
Registered Charity No. 275655; http://www.aab.org.uk
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Legume Science and Practice 2

1st-3rd September 2021

(9 BASIS Points have been awarded as follows: 3CP, 3E and 3PN)

Legumes have the potential to play a substantial role in sustainable agriculture, as a resource for pollinators and birds, in intercropping regimes, providing break crops in rotations, enhancing soil nitrogen levels, accessing soil phosphorous and promoting soil biodiversity. The overall GHG emissions associated with legume foods are low whilst products are highly nutritious and many raw legumes products can be readily stored for long periods without spoilage. As such their role in sustainable food production and security is growing.

This is the second Legumes conference organised by the **AAB 'Cropping And The Environment (CATE)'** specialist group. We have brought together delegates from a broad spectrum of disciplines to explore the role of legumes in sustainable agriculture, with an emphasis on ecosystem service. This is an extremely international event and we are delighted to host an entire day of talks on 'Legumes in Africa'.

Excitingly, a special issue of '*Annals of Applied Biology*' will be associated with this event. Offers of review, research or opinion papers are encouraged for publication in the January 2022 edition of *Annals*. This issue will be free-to-access so will maximise the visibility of your research. This edition will be guest-edited by experts, such as Kairsty Topp (SRUC, Edinburgh, UK), Christine Watson (SRUC, Aberdeen, UK) and Joëlle Fustec (USC LEVA, ESA, INRAE, France). Submissions are required by mid-September 2021 (Please highlight your submissions as 'Legumes 2 Conference Paper') **https://mc.manuscriptcentral.com/aab**

Meeting Virtual Access

The zoom ink for the entire meeting is shown below. Each session will be chaired by a member of the organising committee or an invited guest. If you have any questions please use **Chat box**. The session chair will select questions to ask the speakers. Please use the personal chat option to communicate with other meeting delegates. We are hosting 30minute open discussion sessions at the end of Day 1 and Day 2. These will take place in a different Zoom meeting so please join that link if you would like to discuss anything with poster presenters or other delegates.

Main Meeting Zoom link:
https://us02web.zoom.us/j/83861300556?pwd=Wk9uSnMrbGxLODR2LzQ1Y3FVL1M3Zz09

Parallel Session 4B Zoom link:
https://us02web.zoom.us/j/86050919007?pwd=ZU5hSzdUc1FLK0ZBVC9WdGRwVEFSQT09

Day 1 Discussion Session (17:00 BST)
https://us02web.zoom.us/j/86050919007?pwd=ZU5hSzdUc1FLK0ZBVC9WdGRwVEFSQT09

Day 2 Discussion Session (15:30 BST)
https://us02web.zoom.us/j/85642431158?pwd=ejRLVktEaktKUHU5RGRwWTd3b0hCQT09

WEDNESDAY 1st SEPTEMBER 2021
All times in BST (CET -1hr)

09:50 **WELCOME and INTRODUCTION**
JOËLLE FUSTEC (Ecole Supérieure d'Agricultures, Angers, France)

Session 1: Legume market in Europe and knowledge transfer
CHAIR: JOËLLE FUSTEC (Ecole Supérieure d'Agricultures, Angers, France)

10:00 **Terrena case study: Knowledge transfer for increasing legume surface in Western France**
BERTRAND PINEL (Terrena, France)

10:25 **Markets and price indicators of peas and faba beans in the EU: Results from the H2020 LegValue Project**
BRUNO KEZEYA & MARCUS MERGENTHALER (Fachhochschule Südwestfalen, Soest, Germany)

10:40 **Scenarios for legume protein in European agricultural systems**
IOANNA MOURATIADOU (ISARA, Lyon, France; Leibniz Centre for Agricultural Landscape Research (ZALF), Müncheberg, Germany), HERMINE MITTER (University of Natural Resources and Life Sciences (BOKU), Vienna, Austria), EVGENIA VINOGRADOVA (Humboldt University of Berlin, Germany) , SONOKO BELLINGRATH-KIMURA (Leibniz Centre for Agricultural Landscape Research (ZALF), Müncheberg, Germany; Humboldt University of Berlin, Germany; Leibniz Centre for Agricultural Landscape Research, Müncheberg, Germany), MARTIN SCHÖNHART (University of Natural Resources and Life Sciences (BOKU), Vienna, Austria), NYNKE SCHULP (Vrije Universiteit Amsterdam, Neth ... K STODDARD (University of Helsinki, Finland), CHRISTINE WATSON (S ... ge (SRUC), Aberdeen, UK), & MORITZ RECKLING (Leibniz Cen ... andscape Research (ZALF), Müncheberg, Germany)

Assessing the contribution of legume inclusion in crop rotations to soil health and ecosystem services: A case

10:55 **Legumes Translated: compiling knowledge for developing legume-supported value chains**
DONAL MURPHY-BOKERN (Kroge-Ehrendorf, Lohne, Germany), JENS DAUBER (Johann Heinrich von Thünen Institute, Braunschweig, Germany), LEOPOLD RITTLER, MATTHIAS KRÖN (Donau Soja, Vienna, Austria), JOHANNES SCHULER, HELGA WILLER (Research Institute of Organic Agriculture (FiBL), Frick, Switzerland) & CHRISTINE WATSON (Scotland's Rural College (SRUC), Aberdeen, UK)

11:20 **Multi-criteria assessment of integrating legumes into cropping systems across Europe**
INKA NOTZ (Leibniz Centre for Agricultural Landscape Research (ZALF), Germany), SHEILA ALVES (Teagasc, Ireland), THORSTEN HAASE (Landesbetrieb Landwirtschaft Hessen (LLH), Germany), PAUL HARGREAVES (Scotland's Rural College (SRUC), UK), MICHAEL HENNESSY (Teagasc, Ireland), ANELIA IANTCHEVA (AgroBioInstitute, Bulgaria), JÜRGEN RECKNAGEL (Agricultural Technology Centre Augustenberg (LTZ), Germany), LEOPOLD RITTLER (Donau Soja, Austria), JOHANNES SCHULER (Leibniz Centre for Agricultural Landscape Research (ZALF), Germany), KAIRSTY TOPP (Scotland's Rural College (SRUC), UK), MARJANA VASILJEVIĆ (Institute of Field and Vegetable Crops, Serbia), FRITZ WOLF (Landwirtschaftlicher Beratungsdienst Schwäbisch Hall e.V., Germany) & MORITZ RECKLING (Leibniz Centre for Agricultural Landscape Research (ZALF), Germany)

11:35 **COMFORT BREAK**

Session 2: Soils, N_2 fixation

CHAIR: DONAL MURPHY-BOKERN (Kroge-Ehrendorf, Lohne, Germany)

11:45 **For an integrated strategy in ecophysiology of symbiotic nitrogen fixation and the agronomic ingeneering of legume ecosystemic services**
JEAN-JACQUES DREVON, J ABADIE, L AMENC, D BLAVET (INRAE Ecologie Fonctionnell & Biogéochimie des Sols & Agroécosystèmes, Montpellier, France), O DOMMERGUE (Laboratoire des SymbiosesTropicales et Méditerranéennes, Campus International de Baillarguet, Montpellier France)

12:10 **Increasing soybean productivity by inoculation with locally isolated *Bradyrhizobium* strains under cool growing conditions in Germany**
RICHARD ANSONG OMARI (Leibniz Centre for Agricultural Landscape Research (ZALF), Germany; Humboldt-University of Berlin, Germany), MORITZ RECKLING, MOSAB HALWANI (Leibniz Centre for Agricultural Landscape Research (ZALF), Germany) & SONOKO D BELLINGRATH-KIMURA (Leibniz Centre for Agricultural Landscape Research and Humboldt-iUniversity of Berlin, Germany)

12:25 **Comparing interactive effects of microbial symbionts and nutrients on biological nitrogen fixation, nutrition and yield of mung bean (*Vigna radiata*)**
ELAINE GOUGH, J P THOMPSON, R S ZWART & K J OWEN (University of Southern Queensland, Australia)

12:40 **Modelling the key role of microorganisms in C and N cycles of a cereal-legume agrosystem**
WAHID SLIMANI (High National School of Agronomy, Algiers, Algeria), DIDIER BLAVET (French National Research Institute for Sustainable Development, (IRD) Montpellier, France), HATEM IBRAHIM (University El Manar Tunis, Tunisia), GHILÈS KACI (High National School of Agronomy, Algiers, Algeria), KAREL VAN DEN MEERSCHE, CÉLINE BLITZ-FRAYRET (CIRAD Montpellier, France), ABDESSATAR HATIRA (University El Manar Tunis, Tunisia), FREDERIC GÉRARD, JEAN-JACQUES DREVON (French National Research Institute for Agriculture, Food and Environment (INRAE) Montpellier, France) & MARC PANSU (French National Research Institute for Sustainable Development (IRD), France)

12:55 **Symbiotic performance of indigenous soybean nodulating bradyrhizobia in European cropping systems**
MOSAB HALWANI (Leibniz Centre for Agricultural Landscape Research (ZALF), Germany; Humboldt-University of Berlin, Germany), MORITZ RECKLING (Leibniz Centre for Agricultural Landscape Research (ZALF), Germany; Swedish University of Agricultural Sciences, Uppsala, Sweden), DILFUZA EGAMBERDIEVA (Leibniz Centre for Agricultural Landscape Research (ZALF), Germany; National University of Uzbekistan, Tashkent, Uzbekistan), RICHARD ANSONG OMARI, SONOKO D BELLINGRATH-KIMURA (Leibniz Centre for Agricultural Landscape Research (ZALF), Germany; Humboldt-University of Berlin, Germany), JOHAN BACHINGER (Leibniz Centre for Agricultural Landscape Research (ZALF), Germany) & RALF BLOCH (Eberswalde University for Sustainable Development, Eberswalde, Germany)

13:10 *Recorded short talks to introduce Poster Presentations*

1. **Germination requirements to grow minor pulses in North Europe climates**
SOUKEYE GADIAGA (UniLaSalle, Mont-Saint-Aignan, France) & ALICIA AYERDI GOTOR (UniLaSalle, Beauvais, France)

2. **Strategies to enhance pollination in the field bean, *Vicia faba***
JAKE MOSCROP (University of Cambridge, UK), JANE THOMAS, TOM WOOD (NIAB, Cambridge, UK) & BEVERLEY GLOVER (University of Cambridge, UK)

3. **Growing field beans in ireland: A survey to assess variability in growth and development**
MUIREANN COAKLEY, PAUL PANNETIER, KEVIN MURPHY, BRENDAN REID, DERMOT FORRISTAL & SHEILA ALVES (Teagasc, Carlow, Ireland)

4. **Rye-vetch mixtures – their potential as multifunctional crops**
CHRISTINE WATSON, JOHN BADDELEY (SRUC, Aberdeen, UK), CAIRISTIONA TOPP (SRUC, Edinburgh, UK) & ROBIN WALKER (SRUC, Aberdeen, UK)

5. **Wild pollinators of lupin and faba bean in The Netherlands, and their importance for yield potential**
WILLEMIJN CUIJPERS (Louis Bolk Institute, The Netherlands), EDUARD PETER DE BOER (Bureau FaunaX, The Netherlands), JEROEN BREIDENBACH (Van Hall Larenstein University of Applied Sciences, The Netherlands), JEROEN SCHEPER (Alterra, Centre for Ecosystem Studies, Wageningen University and Research Centre, The Netherlands), MENNO REEMER (European Invertebrate Survey, Leiden, The Netherlands)
DENNIS HEUPINK and UDO PRINS (Louis Bolk Institute, The Netherlands)

13:20 **LUNCH**

Session 3: Pathogens

CHAIR: THOMAS WOOD (NIAB, Cambridge, UK)

14:00 **The challenge of pest and disease management in pulses.**
DIEGO RUBIALES (Institute for Sustainable Agriculture, CSIC, Córdoba, Spain)

14:25 **Potential for improvement of resistance to downy mildew in pea (*Pisum sativum*) and faba bean (*Vicia faba*)**
SANU ARORA (John Innes Centre, Norwich, UK), J E THOMAS, T A WOOD (NIAB, Cambridge, UK), M VIGOUROUX, J CHEEMA, B STEUERNAGEL, G ROBINSON, C MOREAU & C DOMONEY (John Innes Centre, Norwich, UK)

14:40 **Identification of sources of partial resistance to foot rot caused by *Fusarium* spp. in *Vicia faba***
ANNE WEBB, T A WOOD & J E THOMAS (NIAB, Cambridge, UK)

14:55 **Evidence that the faba bean pathogen, *Botrytis fabae*, reproduces sexually in the UK**
TOM REYNOLDS, ANNE WEBB, JANE THOMAS & THOMAS WOOD (NIAB, Cambridge, UK)

15:10 **Mechanisms and resistance sources of *Pisum* spp. collection against *Uromyces pisi***
SALVADOR OSUNA-CABALLERO, NICOLAS RISPAIL & DIEGO RUBIALES (Institute for Sustainable Agriculture (CSIC), Córdoba, Spain)

15:25 **Comparative amplicon sequencing to explore the relationship among land use history, plant health and disease management**
ASFAKUN SIDDIKA, NILOOFAR VAGHEFI, DANTE ADORADA (University of Southern Queensland, Toowoomba, Australia), KHONDOKER DASTOGEER (Tokyo University of Agriculture and Technology, Japan) & Prof GAVIN ASH (University of Southern Queensland, Toowoomba, Australia)

15:40 **COMFORT BREAK**

Parallel Session 4A: Physiology and Genetics

CHAIR: CHRISTINE FOYER (University of Birmingham, UK)

Both parallel sessions will be recorded and made available to all attendees on a private YouTube channel before the end of the event

16:00 **The importance of tertiary roots in young peas for future service legume selection**
LAURE BOEGLIN (Ecole Supérieure d'Agricultures, Angers, France), ANIS M LIMAMI (University of Angers, France) & JOËLLE FUSTEC (Ecole Supérieure d'Agricultures, Angers, France)

16:15 **Genetic variation for seed quality traits in pea: generating novel germplasm**
T RAYNER (John Innes Centre, Norwich, UK), P G ISAAC (IDna Genetics Ltd, Norwich, UK), R OLIAS, A CLEMENTE (Estación Experimental del Zaidín, Granada, Spain) & CLAIRE DOMONEY (John Innes Centre, Norwich, UK)

16:30 **WHIRLY family in soybean (*Glycine max*): subcellular localisation and functional diversity**
BARBARA KARPINSKA (University of Birmingham, UK), SILVANA PINHEIRO DADALTO, AMANDA BONOTO GONÇALVES (Universidade Federal do Ceará, Fortaleza, Brazil), MURILO SIQUEIRA ALVES (Universidade Federal de Viçosa, Brazil), PATRÍCIA PEREIRA FONTESA, LUCIANO GOMES FIETT (Universidade Federal do Ceará, Fortaleza, Brazil) & CHRISTINE H FOYER (University of Birmingham, UK)

16:45 **Genetic variation in transpiration response to vapour pressure dificit (VPD) of two faba bean (Masterpiece & Robin Hood) cultivars using different methodologies**
HEND MANDOUR, IAN C DODD & ELIZABETE CARMO-SILVA (Lancaster University, UK)

17:00 **A new zoom location is open for discussions**

https://us02web.zoom.us/j/86050919007?pwd=ZU5hSzdUc1FLK0ZBVC9WdGRwVEFSQT09**r**

Parallel Session 4B: Legumes in Pasture

CHAIR: GERAINT PARRY (Executive Officer, *Association of Applied Biologists*, UK)

Zoom Link for Parallel Session:
https://us02web.zoom.us/j/86050919007?pwd=ZU5hSzdUc1FLK0ZBVC9WdGRwVEFSQT09

Both parallel sessions will be recorded and made available to all attendees on a private YouTube channel before the end of the event

16:00 **Mixed grass-legume sward nutritional quality improvement as a result of soil liming application**
ROSE BOYKO (Scotland's Rural College, Aberdeen, Scotland; University of Aberdeen, Scotland), ROBIN WALKER (Scotland's Rural College, Aberdeen, Scotland), GARETH NORTON, GRAEME PATON (University of Aberdeen, Scotland) & CHRISTINE WATSON (Scotland's Rural College, Aberdeen, Scotland)

16:15 **Multi-species grasslands stimulate productivity and resilience of a temperate crop-grassland rotation**
GUYLAIN GRANGE (Teagasc, Crop, Environment and Land Use Research Centre, Wexford, Ireland; School of Statistics and Computer Science, Trinity College Dublin, Ireland), CAROLINE BROPHY (School of Statistics and Computer Science, Trinity College Dublin, Ireland) & JOHN A FINN (Teagasc, Crop, Environment and Land Use Research Centre, Wexford, Ireland)

16:30 **Positive legacy effect of previous legume proportion in a ley on the performance of a following crop of *Lolium multiflorum***
AARON FOX (Agroscope, Forage Production and Grassland Systems, Zürich, Switzerland; Agroscope, Molecular Ecology, Zürich, Switzerland), M SUTER (Agroscope, Forage Production and Grassland Systems, Zürich, Switzerland), F WIDMER (Agroscope, Molecular Ecology, Zürich, Switzerland) & VA LÜSCHER (Agroscope, Forage Production and Grassland Systems, Zürich, Switzerland)

16:45 **^{15}N natural abundance and ^{15}N leaf labelling methods provide similar magnitudes of nitrogen transfer from clover to associated grass**
ANDREAS HAMMELEHLE, JOCHEN MAYER (Agroscope, Water Protection and Substance Flows, Zurich, Switzerland), ANDREAS LÜSCHER (Agroscope, Forage Production and Grassland Systems, Zurich, Switzerland), PAUL MÄDER (Research Institute of Organic Agriculture (FiBL), Frick, Switzerland) & ASTRID OBERSON (ETH Zurich, Institute of Agricultural Sciences, Group of Plant Nutrition, Lindau, Switzerland)

17:00 **A new zoom location is open for discussion**

https://us02web.zoom.us/j/86050919007?pwd=ZU5hSzdUc1FLK0ZBVC9WdGRwVEFSQT09

17:30 **DAY END**

THURSDAY 2nd SEPTEMBER 2021

09:50 **WELCOME and INTRODUCTION**

Session 5: Legumes in Africa One

CHAIR: TARIRAI MUONI (Swedish University of Agricultural Sciences, Sweden)

10:00 **Productivity and resilience merits of maize-legume rotation and intercrop systems in Eastern and Southern Africa**
ISAIAH NYAGUMBO (CIMMYT, Mount Pleasant, Harare, Zimbabwe, Africa)

10:25 **Broadening farmer options through legume rotational and intercrop diversity in maize-based cropping systems of central Malawi**
CHIWIMBO P GWENAMBIRA-MWIKA, SIEGLINDE S SNAPP (Michigan State University, USA) & REGIS CHIKOWO (Michigan State University, USA; University of Zimbabwe, Harare, Africa)

10:50 **Integration of tropical legume species into smallholder conservation agriculture systems of southern Africa**
CHRISTIAN THIERFELDER (CIMMYT, Mount Pleasant, Harare, Zimbabwe, Africa)

11:15 **Using functional traits to inform selection of multipurpose legumes for African smallholders**
BEN JACKSON (University of Edinburgh, UK), ERIC PATERSON (The James Hutton Institute, Dundee, UK), HANNAH COOPER, CRAIG STURROCK, SACHA MOONEY (University of Nottingham, UK), ALAN DUNCAN (University of Edinburgh, UK; International Livestock Research Institute, Nairobi, Kenya) & LIZ BAGGS (University of Edinburgh, UK)

11:30 **Biogenic amines in African locust bean (*Parkia biglobosa*) fermented seeds**
NADEGE T KONE, MICHEL Y ESSE, TAGRO GUEHI (Université Nangui, Côte d'Ivoire, West Africa), CAROLINE STRUB (Polytech Montpellier, France), NAWEL ACHIR (Institut Agro, IRC, Montpellier, France), JOEL GRABULOS, CHRISTIAN MESTRES & ELODIE ARNAUD (CIRAD Montpellier, France)

11:45 **GENERAL DISCUSSION**

12:00 ***Recorded short talks to introduce Poster Presentations***

Personal zoom rooms are open for discussion with poster presenters. Please ask the organisers if you would like to have a discussion with a poster presenter

6. **Management of rust in faba bean by crop diversification**
ÁNGEL M VILLEGAS-FERNÁNDEZ, AHMAD AMARNA (Institute for Sustainable Agriculture, CSIC, Córdoba, Spain), JUAN MORAL (University of Córdoba, Spain) & DIEGO RUBIALES (Institute for Sustainable Agriculture, CSIC, Córdoba, Spain)

7. **Is the regulation of nodulation conserved between species at the cell type level?**
HELEN WILKINSON & M L GIFFORD (University of Warwick, Coventry, UK)

8. **Identifying the research gaps in cereal-grain legume intercropping**
ROSA HOLT, CHRISTINE WATSON (SRUC, Aberdeen, UK) & CAIRISTIONA TOPP (SRUC, Edinburgh, UK)

9. **UK-grown potato bean (*Apios americana Medik*): Potential for diet biodiversification and revalorisation as well as suitability for larger scale production**
MADALINA NEACSU (Rowett Institute, University of Aberdeen, UK), ROBIN WALKER (SRUC, Aberdeen, UK), MANDY BARBER (Incredible Vegetables, Ashburton, Devon, UK), MAX COLEMAN (Royal Botanic Garden Edinburgh, UK), CHRISTINE WATSON (SRUC, Aberdeen, UK) & WENDY RUSSELL (Rowett Institute, University of Aberdeen, UK)

10. **Maximisation of production of intercropping pea/cereal crops**
CAIRISTIONA TOPP (SRUC, Edinburgh, UK), JOHN BADDELEY & CHRISTINE WATSON (SRUC, Aberdeen, UK)

12:15 **LUNCH**

Session 6: Legumes in Africa Two

CHAIR: CHRISTINE WATSON (SRUC, Aberdeen, UK)

13:30 **The Legacy of N2Africa: Putting nitrogen fixation to work for smallholder farmers in Africa**
KEN GILLER (Wageningen University & Research, The Netherlands)

13:55 **Rhizobial N2-fixing efficiency is the elicitor of micronutrient accumulation in symbiotic African legumes**
FELIX DAPARE DAKORA (Tshwane University of Technology, South Africa)

14:10 **Panacea: Pathogenomics for enhancing food security in East Africa**
THOMAS WOOD (NIAB, Cambridge, UK), P PAPARU (National Crop Resources Research Institute, Kampala, Uganda), A WEBB, B CORSI & J E THOMAS (NIAB, Cambridge, UK)

14:25 **Closing the yield gaps of Ethiopian faba bean (*Vicia faba* L.) and common bean (*Phaseolus vulgaris* L.)**
KIFLEMARIAM Y BELACHEW (Department of Agricultural Sciences and Helsinki Institute of Sustainability Science, University of Helsinki, Finland; Bahir Dar University, Bahir Dar, Ethiopia; Department of Food and Nutrition, University of Helsinki, Finland), HENRY N MAINA (Department of Food and Nutrition, University of Helsinki, Finland) & FREDERICK L STODDARD (Department of Agricultural Sciences and Helsinki Institute of Sustainability Science, University of Helsinki, Finland)

14:40 **Development of marama bean (*Tylosema esculentum*), an orphan legume, as a crop**
CHRISTOPHER CULLIS (Case Western Reserve University, Cleveland, Ohio, USA), KARL KUNERT, JUAN VORSTER (University of Pretoria, South Africa) & PERCY CHIMWAMUROMBE (University of Science and Technology, Windhoek, Namibia, South West Africa)

14:55 **Evolution of biochemical and nutritional compounds of African locust bean (*Parkia biglobosa*) seeds during their transformation in "Soumbala" in Côte d'Ivoire**
YAVO MICHEL OLIVIER ESSE (Université Nangui, Côte d'Ivoire, West Africa; CIRAD, Institut Agro, Montpellier, France), NAWEL ACHIR (Institut Agro, IRC, Montpellier, France), JOËL GRABULOS, GILLES MOREL, ERIC TARDAN, CHRISTIAN MESTRES (CIRAD, Montpellier, France) & TAGRO SIMPLICE GUEHI (Université Nangui, Côte d'Ivoire, West Africa)

15:10 **GENERAL DISCUSSION and NEXT STEPS**

15:30 **A new zoom location is open for discussions**
https://us02web.zoom.us/j/85642431158?pwd=ejRLVktEaktKUHU5RGRwWTd3b0hCQT09

16:00 **DAY END**

FRIDAY 3rd SEPTEMBER 2021

09:50 **WELCOME and INTRODUCTION**

Session 7: Ecosystem services and Intercropping

CHAIR: CAIRISTIONA TOPP (SRUC, Edinburgh, UK)

10:00 **Biomass accumulation dynamic in soybean-based intercrops: effects of species choice and spatial arrangement**
TIMOTHEE CHERIERE, MATHIEU LORIN & GUENAELLE CORRE-HELLOU (Ecole Supérieure d'Agricultures, Angers, France)

10:15 **Choosing legume as service plant for intercropping with rapeseed based on plant-plant and plant-soil interactions**
XAVIER BOUSSELIN (Agroscope, Nyon, Switzerland), NATHALIE CASSAGNE (Ecole Supérieure d'Agricultures (ESA) Angers, France), ALICE BAUX (Agroscope, Nyon, Switzerland), MURIEL VALANTIN-MORISON (French National Research Institute for Agriculture, Food and Environment, Thiverval-Grignon, France), MARIE HEDAN, MARIO CANNAVACCIUOLO, MATHIEU LORIN & JOËLLE FUSTEC (Ecole Supérieure d'Agricultures (ESA) Angers, France)

10:30 **Assessing the contribution of legume inclusion in crop rotations to soil health and ecosystem services: A case study from UK field trials**
CATRIONA WILLOUGHBY, CHRISTINE WATSON (SRUC, Aberdeen, UK), KAIRSTY TOPP (SRUC, Edinburgh, UK), ROBIN WALKER, ALEX HILTON (SRUC, Aberdeen, UK), PAUL HALLETT, GRAEME PATON (University of Aberdeen, UK) & ELIZABETH STOCKDALE (National Institute of Agricultural Botany (NIAB), Cambridge, UK)

10:45 **Multispecies for multiple functions: Combining four grass and legume species enhances multifunctionality of sown grassland**
MATTHIAS SUTER, OLIVIER HUGUENIN-ELIE & ANDREAS LÜSCHER (Agroscope, Forage Production and Grassland Systems, Zürich, Switzerland)

11:00 **Intercropping heritage and modern wheat varieties with grain legumes**
MERLETTI ARIELE & STEFANO TAVOLETTI (Università Politecnica delle Marche, Ancona, Italy)

11:15 **Evaluation of the effect of grain legumes compared to wheat and oilseed rape on the soil biological functioning: Study of a bio-indicator, the soil nematofauna**
CECILE VILLENAVE, C CHAUVIN (ELISOL Environnement, Congenies, France), A-S PERRIN, T PERROT and A SCHNEIDER (Terres Inovia, Paris, France)

11:30 **GENERAL DISCUSSION**

12:00 **LUNCH**

Session 8: Yield increases and Benefits

CHAIR: ROB CARLTON (De Pinte, Belgium)

13:00 **Managing faba bean to reduce the yield gap: a synthesis from the Legume Gap project**
CHRISTINE WATSON (SRUC, Aberdeen, UK)

13:25 **Bridging the Gap – the Bean Yield Enhancement Network**
CHARLOTTE WHITE, THOMAS WILKINSON (ADAS Gleadthorpe, Mansfield, UK), DANIEL KINDRED (ADAS Boxworth, Cambridge, UK), STEVE BELCHER, BECKY HOWARD (PGRO, Peterborough, UK) & ROGER SYLVESTER-BRADLEY (ADAS Boxworth, Cambridge, UK)

13:40 **Impact of climate on soybean yield stability in Europe**
MORITZ RECKLING & CRISTOPH MÖLLER (Leibniz Centre for Agricultural Landscape Research, Germany)

13:55 **Effect of high CO_2 on the growth and stress tolerance of soybean**
CHRISTINE FOYER (University of Birmingham, UK)

14:10 ***In vitro* and *In vivo* screening through seed defense biopriming with PGPR, Trichoderma and Rhizobia for enhancing green pod quality, growth, production and health of *Phaseolus vulgaris* L. in mid-hill zone of Himachal Pradesh, India**
SHIVANGI NEGI, NARENDRA K BHARAT & HIMANSHU PANDEY (Dr. Y S Parmar University of Horticulture and Forestry, Nauni, Solan India)

14:25 **Forage legumes for future dry climates: Relative yield totals under drought conditions**
MARTIN KOMAINDA (Georg-August-University Göttingen, Germany), MANFRED KAYSER (Georg-August-University Göttingen, Germany; University of Vechta, Germany) & JOHANNES ISSELSTEIN (Georg-August-University Göttingen, Germany; Centre of Biodiversity & Sustainable Land Use, Göttingen, Germany)

14:40 **Secondary agriculture perspectives zinc and iron bio-fortification in chickpea**
GANAJAXI MATH, VIJAYA KUMAR AG & GURUPAD BALOL (AICRP on MULLaRP, University of Agricultural Sciences, Karnataka, India)

14:55 **GENERAL DISCUSSION and NEXT STEPS**

15:15 **END OF CONFERENCE**

Legumes Translated

ÉCOLE SUPÉRIEURE D'AGRICULTURES Angers Loire

ASSOCIATION OF APPLIED BIOLOGISTS

ENQUIRIES

Enquiries concerning the technical content of the Abstracts should be addressed directly to the authors; however, other matters should be directed to the Executive Officer, Dr Geraint Parry (geraint@aab.org.uk) at the AAB Office, Warwick Enterprise Park, Wellesbourne, Warwick CV35 9EF, UK

Session 1: Legume market in Europe and knowledge transfer

Terrena case study: Knowledge transfer for increasing legume surface in Western France

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ABSTRACT

Terrena is the first multi-sector cooperative in France, with 22,000 farmer members and 14,000 employees, among which approximately 300 advisors (crop and animal production) worked. In France, cooperatives are major players in crop advising.

Terrena collects its farmer members' productions (grains, vegetables, wine, milk, livestock, poultry, pigs…), processes them and sells them to supermarket (B to B) or to other food companies. To value farm productions, Terrena has several national trademarks, like La Nouvelle Agriculture (The New Farming). Terrena is highly involved in lupin sector, from crop-breeding to high-value ingredient food products.

In 2021, in a general context of increasing staple food needs and stronger social demand for more sustainable farming, the Board of the cooperative decided to include in its 2030 strategy a goal of 50% of reduction of outside Europe imported soybean meal. Terrena members will be encouraged to crop more legumes (pea, faba bean, lupin, alfalfa, clover…) on their own farms. Today pulses represent less than 5% of the cropped hectares.

To make a success of this goal and others, Terrena has set up a R&D team which, among other objectives, aims at catching, testing, validating, as early and quickly as possible, top-down (from labs) and bottom-up (from farms) knowledge. Terrena has also gathered forward-looking farmers together to build a network of sentinels who are able to innovate, test and popularize innovations (Pinel, 2012).

Besides, during European ReMIX project, Terrena and partners could experiment multi-actor approach (MAA) to create knowledge and solutions, viable for farmers (Hauggaard-Nielsen, 2021). Terrena insists now on the importance of strengthening this MAA, which allows every actor to understand the constraints of the different links of the value chain and thus allows the transformations of farming systems.

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Markets and price indicators of peas and faba beans in the EU: Results from the H2020 LegValue Project

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ABSTRACT

Legume markets are currently fragmented and non-transparent in many European countries. This might contribute to low market incentives for growing legumes. By increasing market transparency, market entrance is facilitated for new players in the cultivation and utilisation of legumes. To this end, paying more attention to the market analysis and spreading information of legumes might be helpful for economic actors. Furthermore, the identification, development and use of different price indicators to support relevant stakeholders, in particular farmers to better sell their legumes, might be incentivize the interest to grow and to market legumes.

The project LegValue has dedicated a work package to reach two goals with respect to market transparency: to conduct a market analysis and to develop price indicators for legumes. For the market analysis, data were obtained from different statistical databases and were used for a basic quantitative description of EU-legume markets. Elements used include cultivated areas, yields, production volumes, domestic consumption, imports and exports. Expert knowledge was employed to qualify these data, in order to explain the differences in production volume, use of products and customer preference. For the price indicators, three approaches have been developed. The first approach was based on a multiple regression analysis with the observed prices of substitute feed like wheat and soybean meal. The second approach was based on the determination of the feed value of legumes in pig fattening using a replacement method. The third approach is to derive a price indicator from the foreign trade data as a unit value.

As result for the market analysis, it has been shown that processors as the main players in this commodity market have a major influence. An in-depth analysis of foreign trade data of legume highlighted factors that influence the legume market in the EU. They might be useful for policy development. As a result, for the price indicators, it was found that the highest value for legumes is achieved in foreign trade, followed by the feed value in intra-farm use. This shows that the current market price reporting of grain legumes has been permanently and systematically undervalued. It is recommended to use the three price indicators as price bands for the negotiation of legume prices between market actors.

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Scenarios for legume protein in European agricultural systems

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ABSTRACT

European consumption of plant proteins depends greatly on imports of soybean, with more than 70% of high value-protein currently being imported (Watson *et al*., 2017). Changes in international trade and diets affect global protein markets and lead to deforestation and imbalance of agricultural systems. Intensive and specialised agriculture contributes to negative environmental impacts and is vulnerable to climate change. Increasing domestic production of legumes in Europe could be a strategy to address these challenges. Diversification with legumes could increase the resilience of European farming systems, reduce fertilizer and pesticide use, enhance biodiversity and ecosystem services and contribute to healthy nutrition.

But what is the actual potential for expanding legume production in Europe and what are the current barriers at the different scales (field, farm and food sector)? How large are the co-benefits from legumes and who are the beneficiaries? How will potentials, co-benefits, barriers and trade-offs evolve in the future (climate change, changes in global trade, consumer preferences)?

In this talk, we will present a set of novel scenarios for legume proteins with a focus on agricultural and food systems in Europe. The scenarios are developed in consistency with wider narratives on global change (SSPs, Popp *et al*., 2017, Riahi *et al*., 2017), European agriculture (Eur-Agri-SSPs, Mitter *et al*., 2019; 2020) and the food system (e.g. Springmann *et al*., 2018). They sketch alternative pathways for the future evolution of protein supply and demand in Europe considering, for example, changes in diets, technological evolution and agricultural management, as well as protein global markets. The scenarios are co-developed in an interactive workshop guided by senior experts in the frame of the projects 'Protein Paradoxes' and 'LegumeGap'. We present a summary of the developed scenarios, with a focus on the potential of legumes to enhance sustainability and diversification under different framework conditions in Europe.

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Legumes Translated: Compiling knowledge for developing legume-supported value chains

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ABSTRACT

Legumes Translated is the thematic network in Horizon 2020 dedicated to legume production and use. Thematic networks are Coordination and Support Actions that stimulate the exchange of knowledge that supports sustainable agriculture. They are a key element of the European Innovation Partnership for Agriculture (EIP Agri) complementing both operational groups and Horizon 2020/Horizon Europe research and innovation projects with emphasis on trans-national and cross-border knowledge interaction. Legumes Translated supports the European Protein Plan (European Commission, 2018) in particular. The overall goal is to support the production and use of legume crops in Europe as part of an overall change in protein sourcing and use (Donau Soja, 2018).

The challenges that legume crops can help address are well-documented: the need for more diversity in cropping; yield stagnation in cereal-dominated systems (Watson *et al*., 2017); and a 29% deficit in tradable plant protein in the European Union (EU) that is currently met by about 35 million tonnes of soybean equivalent imported from the Americas (Murphy-Bokern *et al*., 2017). Europe's protein deficit is a fundamental challenge to the resilience, acceptance and performance of our agri-food systems. There are indications that Europe is now on the cusp of a significant change manifest in the positive political response to the Donau Soja European Soya Declaration and the European Commission's work on Europe's protein balance. Against this background, Legumes Translated has three underlying principles: empowerment of innovators through understanding; practice- and research-based sources of knowledge are mutually supportive; and cropping and farming system innovation must go hand-in-hand with corresponding value chain developments (especially in livestock).

The project concept is based on the networking of 13 existing groups of farmers and other innovators (actor groups) within an international framework provided by seven sub-networks focused on cool-season grain legumes, soy, food, pigmeat, poultry, dairy and beef, and aquaculture. These promote increased flow of practical information from actor groups between geographic areas. The support of three analytical work packages enables exchange and rigorous knowledge synthesis and compilation at four levels: specific actor group farming systems; between related actor groups within seven networked technical areas of the agricultural sector (sub-

networks called transition networks); exchange between research-based partners and the policy community; and between actor group-level knowledge and the policy community.

Establishing and running an efficient thematic network is a complex task that must be completed in a relatively short 3 year project period. Legumes Translated supports and benefits from the 'bottom-up' multi-actor approach that is balanced by the use of a 'top-down' approach to analysis of information. Within the first six months, our actor groups had provided detailed information on their activities and ambitions and we had successfully established seven vibrant transition networks. Focus is essential for a three-year project and so we completed examples of our major outputs: practice notes/abstracts and videos within six months of starting. The synthesis of information from actor groups within the transition networks has identified four areas of demand for knowledge: the farm-level impact of introducing grain legumes into cropping systems; the nutritional and economic valuation of legumes for animal feed; knowledge exchange for soya production and use; and the testing/validation of environmental claims made corporate social responsibility schemes.

Responding to the European Protein Plan, the European Legume Hub is a major project output that has strategic relevance for the whole legume development community going forward. It is a community-owned publishing platform for sharing knowledge that will last after the project is completed. The Hub's registered users are a community of members of the European Legume Hub Association that governs the Legume Hub. The project experience shows that:

1. This type of networking should be treated as a highly strategic and skilled activity that requires deep insight, understanding, and an enterprising approach.
2. Participants must want to extend their horizons beyond the traditional practitioner, researcher and advisor boundaries.
3. A focus on decisions made within value chains provides a framework for extracting knowledge and focusing it on the needs of users.
4. A systematic analysis of practice-based knowledge is yielding insights into value chain fundamentals overlooked by research-focused discussions.

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Multi-criteria assessment of integrating legumes into cropping systems across Europe

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ABSTRACT

Integration of legumes into European agricultural systems would diversify the highly specialized cropping systems that are dominated by cereals and increase resource-efficiency of agricultural systems. By providing high quality protein for food and feed as well as regulating and supporting services, legumes contribute essential ecosystem services.

In order to assess the overall effects of legumes in agricultural systems, it is necessary to consider how legumes are integrated in cropping systems and evaluate the impacts of this integration. As legumes influence the production of other crops in the rotation and as the interaction of legumes are multiplex, an assessment of the cropping system that considers multiple criteria is required.

The objective of this work was to assess the impacts of changes in crop rotations through the integration of legumes using cropping systems implemented in practice. We used a multi-actor approach to incorporate the knowledge of a range of legume-experienced actors representing value chains with soybean, pea, faba bean, lupin and forages for food and feed and evaluate thereby the role of legumes in crop rotations of diverse systems from Ireland in the West to Ukraine in the East.

Within the research process we firstly identified region-specific crop rotations with cultivation techniques based on expert opinion in the 17 different study areas. One rotation representing the current farming without legumes and at least one alternative legume-based crop rotation was specified per region. Secondly, a valid set of indicators was developed, including environmental, economic and agronomic

indicators. The indicators were calculated for each cropping system at the rotational level, considering pre-crop effects i.e. adapted N fertilizer application rates and yields. Finally, the cropping system assessment compared current farming practices to legume-based alternatives. Trade-offs and synergies between different indicators e.g. gross margins and N fertilizer use were identified.

On average, crop rotations with legumes reduced nitrous oxide emissions by 21% and 26% and N fertilizer use by 26% and 45% in arable and forage systems, respectively. While protein output was increased by 13% and 5%, energy output was reduced by 10% and 9% in arable and forage systems. Gross margin effects of introducing legumes were variable and site specific. Consideration of the full economic value of the crops as feed, subsidies for legumes, and the application of carbon taxes increased the relative performance of the legume-supported systems.

The presented cropping system assessment within a multi-actor approach enables an exploration of the opportunities and challenges for integrating legumes in European crop rotations considering the views of local actors and can thereby provide multi-criteria guidance on the validation of potential alternative strategies.

Session 2: Soils, N2 fixation

For an integrated strategy in agronomy of symbiotic nitrogen fixation and ingeneering of legume ecosystemic services

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ABSTRACT

Fewer chemical inputs, as fertilizers or pesticides, become of paramount importance for the safety and impact on the environment of agricultural production of food. This implies new requirements with regard to the selection of legumes for grain-cropping systems and their inoculation with beneficial symbiotic and rhizospheric microbes. Low phophorus availability limits crop yield in about 40% of the world's arable land, most particularly for leguminous crops when their growth depends upon symbiotic N_2 fixation (SNF). Therefore, our work aims to increase the phosphorus use efficiency (PUE) for SNF, and its contribution to a more effective coupling between the P and N bio-geochemical cycles in agriculture and forestry. For this purpose, the FTM interdisciplinary research strategy has been developped in agro-ecosystems of the Mediterranean basin and tropical Africa, with the support in particular, of the Great Federative Project FABATROPIMED of Agropolis Fondation under the reference ID 1001-009. The overall objective is to increase the benefit of grain-legumes for cereal systems and the environment by promoting the interaction between soil beneficial microbes for plants to acquire and use N and P most efficiently. The field activities include a participatory approach with farmers in reference agro-ecosystems offering a wide range of agroclimatical and socioecological situations. The nodular diagnosis revealed large spatial and temporal variation of SNF that will be illustrated with results for faba bean in agroecosystem of South of France. Functional genomics and ecology could be linked through the study of *Myo*-inositol hexakisphosphate (phytate) as the main source of organic P in soils. Only phytases are able to hydrolyse phytate efficiently into inorganic Pi, the only P form known so far as bio-available for plants. Phytase genes, both histidine acid and *beta*-propeller, were found is some rhizobia. Their expression within nodule infected-cells was shown by *in situ* RT-PCR. Plant phytase-genes were also found in nodules, and shown to vary significantly under P-deficiency among recombinant inbred lines of *Phaseolus vulgaris* that are contrasting in their PUE for SNF. It is concluded that yields of legume, and their stabilization, could be improved through an integrated strategy on their PUE for SNF and ecosystemic services.

Increasing soybean productivity by inoculation with locally isolated *Bradyrhizobium* strains under cool growing conditions in Germany

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ABSTRACT

Soybean cultivation is still new in Germany and commercial inoculum is mainly used to inoculate field-grown soybean. However, the symbiotic efficiency of these inocula is often low. Native isolates of rhizobium are sometimes better adapted to the regional soil, climate, or cultivar than the commercially available inoculum. The objective of this study was to evaluate the efficacy of locally isolated *Bradyrhizobium* strains to enhance soybean productivity in varying growing conditions of Northeast Germany.

Three *Bradyrhizobium* isolates (GMF14, GMM36, GEM96), which were isolated from German soils were tested in combination with three soybean cultivars (Merlin, Sultana, Siroca) in field and greenhouse conditions. Non-inoculated soybean was used as a negative control and *Bradyrhizobium diazoefficiens* USDA110 inoculation was used as a positive control. Two moisture levels were set for the pot experiment, i.e. irrigated condition (80% field capacity) and drought condition (40% field capacity) using soil from the same location as the field experiment. In the field experiment, soybean plants were cultivated under rainfed conditions. Nodulation parameters, nitrogen (N) uptake, and biomass yield were measured in both studies. Grain yield and protein content in the kernels were determined at harvest.

We observed a higher nodule number in the greenhouse experiment compared to the field experiment, independent of the *Bradyrhizobium* strain. Generally, inoculation with the present strains resulted in up to 68% shoot N uptake in the greenhouse study and up to 39% in field conditions. Consistently higher significant nodule number and nodule dry weights were observed in GMF14 and GMM36 under irrigated conditions. However, under drought conditions, minimal differences in nodulation were observed among the strains. Inoculation with strain GEM96 induced the highest nodulation in field conditions. Altogether, inoculation with the present isolates significantly increased protein content, grain yield, thousand-grain weight, and pod number up to an average of 24%, 32%, 17%, and 31%, respectively. Among the tested strains, GEM96 inoculation had the highest protein content of 412 g kg^{-1} and was statistically similar to USDA110 and GMF14. While USDA110 was effective when inoculated to Sultana and Siroca, strain GMM36 and GEM96 inoculation to Sultana and Siroca, respectively resulted in statistically similar grain yields. Thus, GMM36 and GEM96 are promising strains that potentially could increase soybean yield in Northeast Germany. The observed *Bradyrhizobium*-soybean cultivar affinity, modulated by soil moisture suggests that the symbiotic performance of these isolates could be optimized based on their combination with specific soybean cultivar under suitable climatic conditions.

Comparing interactive effects of microbial symbionts and nutrients on biological nitrogen fixation, nutrition and yield of mung bean (*Vigna radiata*)

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ABSTRACT

Mung bean (*Vigna radiata*) is a short season high value summer legume cultivated in the sub-tropical grain region of eastern Australia, and exported predominantly to the Asian subcontinent. It is inoculated with *Bradyrhizobium* sp. for efficient nodulation and biological nitrogen fixation (BNF). Limitations to BNF in the region include poor nodulation and low soil phosphorus (P). Arbuscular mycorrhizal fungi (AMF) are soil borne beneficial micro-organisms that associate with the roots of most land plants. One of the many benefits they provide is to improve the uptake of poorly mobile nutrients such as P and Zinc (Zn) to the plant via their extraradical hyphae extending past the nutrient depletion zone of the root. Our previous research demonstrated the synergistic effects between AMF and rhizobia improving BNF, nodulation, plant nutrition, biomass and yield.

We wanted to investigate the contribution of both AMF and fertiliser P to BNF efficiency and yield in mung bean. A factorial designed glasshouse experiment was carried out between treatments of AMF, rhizobia, N, P and Zn in a pasteurised vertisol. Variables of BNF including N derived from the atmosphere (% Ndfa), fixed N, nodulation, plant nutrition, biomass and yield were measured at the vegetative and reproductive stages.

Our results demonstrated that the combination of AMF and P significantly improved BNF and biomass at the vegetative stage ($P<0.001$). At the reproductive stage, AMF significantly improved BNF, nodulation, biomass and yield to a level greater than or equal to fertilisation with P, with no further benefit on combining both ($P<0.001$). Inoculation with AMF also increased the concentrations of P and Zn in the shoots significantly greater than the application of the nutrients alone ($P<0.01$). Interactions occurred between rhizobia x N fertiliser, whereby rhizobia increased biomass and yield greater than fertilisation with N alone.

Arbuscular mycorrhizal fungi are a valuable natural resource associated with many leguminous crops. Management of AMF in vertisols, together with inoculation with *Bradyrhizobium,* may improve BNF, plant nutrition and yield of mung bean in a sustainable manner while reducing the dependence on excessive fertilisers.

Modelling the key role of microorganisms in C and N cycles of a cereal-legume agrosystem

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ABSTRACT

Most of the models published over past decades and predicting the soil organic matter transformation in the C and N cycles are based on parameters not always linked to the environment and underestimate the role of microorganisms. They are often over parameterized, which can give multiple solutions for flow calculations between state variables. This work proposes a parsimonious but process-based model centered on the functioning of living organisms, in order to calculate flow parameters using data on C and N stocks in decomposers, plant organs, symbiotic microorganisms, and the soil compartments in a Mediterranean wheat-legume agrosystem.

In term of modelling approach, the behavior of a wheat-legume agrosystem over time was modelled as a complex system according to the System dynamics (SD) approach (stocks, flows, feedback loops ...).

Concerning the model development and structure, the whole model contains a plant and Symbiont module coupled with the core MOMOS module (Modelling of Organic transformations by Micro-Organisms of the Soil). A Field experiment was done in 2011, located on INRA UE Diascope station, Melgueil, France (43°37′32″N, 3°59′20″E). Three cropping systems without fertilizers were compared : faba bean (Vicia Faba)/ durum wheat (Triticum durum)/ Intercropping faba bean–durum wheat. Several data were collected for model calibration (Daily air temperature and rainfall; for soil : CO_2 production; C and N content; microbial C, N and biomass; for plants and symbionts : roots, shoots, grains and nodules biomasses, C% and N% ...).

The application of the model on the data set provided various results such as: i) Quick exchanges of N between microorganisms and other compartments during the growing season; ii) The soil of intercropping system appears as a sink of labile C; iii) The efficiency of symbiotic nodules for N_2 fixation and plant growth is improved in intercropped faba bean.

Based on the microbial functioning scheme of MOMOS validated in mediterranean conditions, the parsimonious model presented enables realistic estimations essential in agro-ecology and global change predictions such as plant growth and nutrition, and sometimes very difficult to measure, such as microbial and root respirations, continuous emission and sequestration of greenhouse gas CO_2, humus storage, N losses and N exchanges between decomposers, plant roots and (for legumes) nitrogen-fixing symbiotic nodules. This model deserves to be tested over longer durations, in various ecosystems, soils and climates for predictions and modelling evolution.

Symbiotic performance of indigenous soybean nodulating bradyrhizobia in European cropping systems

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ABSTRACT

To realize the potential of soybean [*Glycine max* (L) Merrill] as a protein-rich crop in central Europe, soybean requires improvement of compatible soybean nodulating Bradyrhizobia (SNB). Little is known about the symbiotic potential of indigenous SNB in Central Europe and the interaction with an SNB inoculum from commercial products. Eleven sites representing five soybean history (soybean cropping interval; SCI) were assessed, with the aim to assess: (i) the variation among SCI for capacity of indigenous SNB and the symbiotic performance of soybean; and (ii) the impact of a commercial inoculate containing elite Bradyrhizobia strains on the symbiotic performance of soybean, using soils with and without soybean history. This study was carried in a pot experiment under controlled conditions in a growth chamber. The soil samples were collected from sites without soybean history and sites with soybean history in 1–4 years SCI. Soybean cropping interval (SCI) refers to year(s) since the last soybean cultivation.

Compared between the two soil groups, although nodulation occurred in all soil samples, the plant grown in soil with soybean history developed significantly more root nodules and high plant tissue nitrogen. Moreover, these parameters along with the leghemoglobin content were variable among soils with 1–4 years SCI and did not show a trend between the years of SCI. With inoculation, all soils with no soybean history showed a significant increase in nodulation rate, leghemoglobin content, and soybean tissue nitrogen concentration. Response to inoculation varied significantly between the locations in soils with previous soybean cultivation history. Inoculated soybean grown in the soils with slightly loamy sand type in Müncheberg had significantly more nodules and was accompanied by high green tissue nitrogen concentration, than the non-inoculated plants. However, no significant improvement in nodulation rate and tissue nitrogen concentration was observed for inoculated soybean grown in the soils with medium loamy sand type in Fehrow.

These data suggested that introduced SNB strains remained viable in the soil and still symbiotically competent with soybean for up to 4 years thereafter. However, the

symbiotic performance of the introduced SNB in the soils was not mostly sufficiently high to make the inoculation of soybean unnecessary; hence, the use of commercial inoculants can ensure constant nodulation and symbiotic performance. It is worth mentioning here that these adapted introduced SNB strains in the soil of central Europe are promising candidates for inoculant development and represent a contribution towards the successful cultivation of soybean in central Europe.

Recorded short talks to introduce Poster Presentations

1–5

Poster 1
Germination requirements to grow minor pulses in North Europe climates

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ABSTRACT

In French northern cropping systems farmers used to cultivate faba bean and protein peas, but face to a high yield decrease and variability over years, legume crops are less cultivated, inducing a lack in the rotations (Voisin *et al*., 2014). The changes in food habits like veganism and the environmental consciousness of the society has increased the interest on vegetal proteins. Besides, there is an interest on local food, but few food crops with high protein content are currently cultivated in the North of France. Nevertheless, a wide diversity of pulses exists in the world but only few species are cultivated in temperate oceanic influenced climates (Smýkal *et al*., 2015; Ayerdi Gotor & Marracini, 2015). This study aims to provide information about the minimal temperature required for minor pulses to germinate to determine the possible sowing date and establish the potential harvest dates in oceanic temperate climates. This a first step to determine the viability of growing these new species in new areas to give a panel choice both to farmers and consumers.

Germination tests have been conducted with seven minor pulses and a control major pulse: *Cajanus Cajan*, *Vigna angularis*, *Vigna unguiculata*, *Macrotyloma uniflorum*, *Lablab purpureus*, *Vigna radiata*, *Phaseolus coccineus* and *Cicer arietinum* at several temperatures ranging from 5°C to 25°C to evaluate the germination ability and vigour of seedlings.

Results show that the highest is the temperature the quickest is the germination speed and vigor of the plantlets. Within all the species tested none of them has started the germination in temperatures below 12°C after 10 days of observation. All the species were able to germinate with temperatures above 15°C but it took much more time at 15°C compared to 25°C. At 25°C chickpeas grains melted after 2 days at this temperature whereas minor pulses had a quick growth.

These first results show that sowing these minor pulses in North France conditions should require to have a high soil temperature that will be reached only at the end of April or beginning of May. This is already the case when sowing Soybean in these regions. Then the differences between the pulses and the potential yield will be determined by the length of the crop.

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Poster 2
Strategies to enhance pollination in the Field Bean, *Vicia faba*

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ABSTRACT

With pollinator populations in decline, and our nutrition ever more dependent on insect pollination, it is vital that we develop crops which are both attractive and beneficial to pollinators (Aizen *et al.*, 2008). The field bean, *Vicia faba,* is one economically important crop which benefits greatly from bee pollination. Studies have shown that bee pollination greatly enhances the yield of *V. faba*, with some reporting yield increases of over 50% compared with plants grown in the absence of pollinators (Bishop *et al.*, 2016)(Nayak *et al.*, 2015). Studies have also shown that increased bee visitation can decrease yield variability in the crop (Bishop *et al.*, 2016), suggesting that yield instability may be linked to insufficient pollination. To be able to advise breeders on which floral traits may help to attract pollinators, we need to determine how much floral variation exists between current *V. faba* lines, and which traits influence pollinator behaviour.

Previous research has identified variation in some floral traits of this crop, which can influence pollinator attraction (Bailes *et al.*, 2018). This project seeks to further explore strategies for optimising field bean flowers, to provide maximum energetic reward to pollinators for minimum foraging energy expenditure. Current work has focused on identifying variation in floral traits of novel commercial *V. faba* lines*,* and the influence of *V. faba* wing spots on the behaviour of *Bombus terrestris,* the buff-tailed bumblebee. Future work will investigate the responses of pollinators to extremes of variation in specific floral traits in both laboratory conditions and on a field scale.

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Poster 3
Growing field beans in Ireland: A survey to assess variability in yield

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ABSTRACT

Field beans (*Vicia faba* L.) are a high protein legume well-suited to the Irish climate with a relatively high yield potential (6–8 t ha^{-1} for winter and 4–7 t ha^{-1} for spring varieties). Nonetheless, the crop was only grown on a limited scale until 2014, with an average of 17,650 tonnes produced from 3,183 ha annually in the period of 2009–2014 (FAOSTAT, 2019). The perceived variability in yield, inadequate varietal development and limited specific agronomic information (including disease control) in the Irish context are the main reasons associated with the lack of interested in the crop. In 2015, as part of the EU Agreement on CAP Reform and to counteract the huge dependence in the EU on imported protein for use in animal feeds, the Protein Aid Scheme for nitrogen fixing crops (or protein crops) was introduced in Ireland (DAFM, 2014). As consequence, the harvested area of field beans quadrupled (*c.*11,467 ha year^{-1} for the period of 2015–2017). To maintain and to potentially increase the field beans area, detailed information about the overall performance of the crop in Ireland is needed and the specific factors causing variability in that performance identified.

To address the deficit in knowledge regarding the variability of crop growth and development in grower's fields, 44 commercial crops, comprising winter and spring sown field beans, were surveyed over the 2018–2019 and 2019–2020 seasons. An online survey comprising spring sown field beans was also performed in 2020. The output of this study will give a greater understanding of variability and the factors influencing it and consequently the scope for improved crop management and better targeting of future research to optimise production on Irish soils and climate.

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Poster 4
Rye-vetch mixtures – their potential as multifunctional crops

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ABSTRACT

Reducing the environmental impact of farming systems whilst maintaining or improving production and profitability is central to the concept of sustainable intensification. Mixture of rye and vetch have a the potential to achieve this due to their multifunctional end uses; they can be grown as an overwinter cover crop, taken to a silage wholecrop or allowed to ripen, for use as anaerobic digestion feedstock or for novel protein extraction technology. This inherent flexibility gives farmers much more potential to grow rye/vetch mixtures profitably than cover crops that can only be ploughed in spring. Here we explore the effect of growing rye vetch mixtures on the yield and the quality of silage.

Trials of pure stands of winter rye (*Secale cereale* var. SU Performer), winter vetch (*Vicia sativa*, var. Early English) and two mixtures of these were sown in late September at a site in Aberdeenshire in the 2018/19 and 2019/20 growing seasons. Sole crops of vetch and rye were planted as well as mixtures containing either 80% rye + 20% vetch or 60% rye + 40% vetch. Background P & K applications of 70 kg ha^{-1} were made around sowing time, but no N was applied. The crops were overwintered and grown through the following season until the rye had reached the dough stage (Zadoks 83–85). After manual chopping, samples were quadruple wrapped in black polythene sheeting to achieve an airtight seal with a sugar additive to produce silage.

In terms of the total yield of the sole crops, rye yield was approaching double that of vetch. However, the greatest yields were from the mixtures with Rye 60 yielding significantly more than sole rye, but not different from Rye 80. The protein content of vetch silage was about four times greater than that of rye silage, while silage from the mixtures had intermediate levels. However, when protein yield was calculated many of these differences disappeared. The silage protein yields of vetch and the two mixtures were not significantly different, whereas that of rye silage was significantly lower and only about one third of that of the highest protein yield in Rye 60. Metabolisable energy (ME) yield followed a similar pattern to total yield in that vetch had a significantly lower ME yield than the other treatments. The greatest yields were seen in the two mixtures and that in Rye 60 was significantly greater than that in pure rye. These differences in silage parameters are probably due at least in part to the significantly lower fibre levels in the vetch compared with rye (data not shown). Thus rye-vetch mixtures give greater silage yields and also the greatest protein and energy yields, although if protein production alone was a priority then sole cropped vetch would also be a reasonable option.

Acknowledgements

The trials team at Aberdeen who established, monitored and harvested the trials, and the famer who kindly hosted the trials on his farm. We acknowledge the Loirston Trust, EU H2020 ReMIX (Redesigning European cropping systems based on species mixtures, https://www.remixintercrops.eu/), EU H2020 Legume Translated (Translating knowledge for legume-based farming for feed and food systems, https://www.legumestranslated.eu/), and Scottish Government Strategic Research programme for supporting this work.

Poster 5
Wild pollinators of lupin and faba bean in The Netherlands, and their importance for yield potential

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ABSTRACT

The re-introduction of grain legumes in crop rotations may contribute to biodiversity and ecosystem services in several ways. In the past, crops like faba bean were grown in much larger areas of Europe (Watson *et al.*, 2017). In the Netherlands, the disappearance of grain legumes from cropping systems coincided with the disappearance of other flowering crops, like flax and caraway seed. This has made the landscape much less attractive for nectar and pollen foraging species. Flowering crops can play a role in the maintenance of specific wild pollinator communities, provided that also other prerequisites are fulfilled. Fluctuating yields can have many different causes, but may partly result from a lack of pollinators in certain years. For farmers, it could be beneficial to stimulate pollinators by creating a favourable environment with both nesting facilities and food sources. A greater variety of pollinating species, could contribute to a more resilient farming system. However, wild bee populations are declining at an alarming rate: in the Netherlands, of 331 native bee species, 181 are threatened. Recent data on pollinating species of new protein crops like faba bean and lupin are scarce. In this study, we investigated the presence of pollinators during bloom of faba bean (*Vicia faba*) and white (*Lupinus albus*) and blue lupin (*L. angustifolius*) on three different farms, during a 2 year period. Historical data on flower-visiting behaviour and pollen collection of wild bee species were reviewed. In 2019 and 2020, field experiments were carried out on an organic farm, to investigate the contribution of pollinators to the yield of faba bean (cv. Pyramid) and white lupin (cv. Feodora), using exclosures, inclosures with bumble bees and open pollination.

A total of 72 species of pollinating insects were found during two years at the three locations. Among them were three species of wild bees, five species of bumblebees and 16 species of hoverflies. Of these three main groups of pollinators, an average of 19, 27 and 26 pollinators were found per 100 m. transect in faba bean, white and blue lupin. Bumblebees were the most frequent pollinators in faba bean and white lupin;

hoverflies in blue lupin. Based on historical data, potential wild pollinators of faba bean (16 species), and lupin (10 species) were identified.

The field experiments with faba bean, in which insect-free outdoor tents were used to create exclosures, inclosures (with bumblebees) and natural (open) pollination, showed large and significant differences in yield, when faba bean was cultivated with and without pollinators. In 2019, in the exclosures, yield of faba bean variety Pyramid was reduced to 2.5 t ha^{-1} (85% DM), compared to 7.2 t ha^{-1} in inclosures with bumblebee pollination, and 6.9 t ha^{-1} in a situation with natural (open) pollination. In 2020, yields were strongly reduced by aphids, especially inside the cages where no natural enemies (ladybirds and hoverflies) were present. In this year, faba bean yield with open pollination was 3.5 t ha^{-1}, compared to 1.7 t ha^{-1} in cages with bumble bees, and 0.1 t ha^{-1} in cages without insect pollination. Average yields of white lupin (cv. Feodora) were 1.9 t ha^{-1} in 2019 and 1.3 t ha^{-1} in 2020, with no significant differences in yield between pollination treatments.

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Session 3: Pathogens

The challenge of pest and disease management in pulses

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ABSTRACT

Legumes, as any crop species can be constrained by a long list of pests and diseases. This includes rusts, mildews, ascochyta blights, anthracnoses, botrytis gray molds, vascular wilts, root rots, viruses, bacteria, nematodes, parasitic weeds and insect pests (Rubiales *et al*., 2015). Their incidence and prevalence varies regionally as affected by agro-climatic conditions and crop management. A number of control strategies are in place for some of them, their applicability facing technological and economic limitations. Rather than being eradicated, many of these constraints are expanding and might become more critical in the predicted scenario of decrease pesticide uses. Also, climate change is affecting their relative importance impacting their geographic distribution and frequency of outbreaks (Skendžić *et al*., 2021).

All this call for integration of available management strategies, with genetic resistance playing a core role. The state of the art of current achievements and limitations in the control and resistance breeding of a number of examples of pests and diseases of major pulses will be presented and critically discussed.

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Potential for improvement of resistance to downy mildew in pea (*Pisum sativum*) and faba bean (*Vicia faba*)

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ABSTRACT

Downy mildew (*Peronospora pisi* on pea, and *Peronospora viciae* on faba bean) infection is a major constraint on crop productivity. Both yield and quality are affected and increases in soil-borne oospore populations eventually limit future cropping. In pea, seed treatment offered effective protection against the soil-borne primary systemic phase in the past but there was limited opportunity to control later infections on pods and foliage with sprays. Regulatory constraints on the seed treatment limited its usefulness, and this product has now been withdrawn. In faba bean, seed treatment is not available, so primary systemic infections develop readily, spreading spores to foliage. The effective sprays currently available are relatively expensive, and repeat sprays are often necessary. Thus the availability of high level, stable resistance is an important breeding target in both crops. Pathotypic variants have been identified for the pea-infecting species, associated with a loss of resistance in some resistant material when exposed to a different pathogen population. In the case of faba bean, the limited number of commercial cultivars show a high level of downy mildew resistance which appears stable currently. Screening diverse germplasm of both crops is thus essential to identify novel resistance sources, stack the gene combinations in a single host genotype, and maximise the chances of longer-term stability. In pea, two different sources of resistance from accessions JI 15 and JI 85 were identified in an initial screen. Both are *Pisum sativum* but JI 85 is positioned within the most diverse group of exotic *Pisum* accessions, based on a genetic 'Structure' plot (Jing *et al.*, 2010). A diversity panel of >200 lines selected from the JIC *Pisum* germplasm resource was screened with pathotypes characterised on a set of differential cultivars. This screen revealed ~50 lines with no observable disease and further lines with very high levels of partial resistance. Repeat screens with additional pathotypes from new field outbreaks will predict the likely durability of these new sources of resistance. Genomic sequencing of the candidate resistance genes identified in pea is providing information on their association with resistance traits. In faba bean, a QTL on chromosome 1 has been associated with partial resistance to downy mildew. Additional screens of 100 accessions, many originating from ICARDA, using seedling tests with a 2018 field population of downy mildew, have identified seven inbred lines with near-complete resistance. Detached leaves from these have been tested with additional pathogen isolates collected in 2019, in order to select the most resistant line for development of a mapping population. Identification and characterisation of multiple resistance sources for pyramiding provides the best option for future control of downy mildew in both crops.

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Identification of sources of partial resistance to foot rot caused by *Fusarium* spp. in *Vicia faba*

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ABSTRACT

Foot rot in *Vicia faba* is a disease complex caused by soil-borne fungi and oomycetes, e.g. *Aphanomyces euteiches*, *Pythium* spp., *Rhizoctonia solani*, *Phoma* spp. and multiple *Fusarium* species (Sillero *et al*., 2010, Kurmut *et al*., 2002, Clarkson *et al*., 1978). Symptoms include stunted growth, chlorosis and dark brown or black lesions of hypocotyl and parts of the root system. Diseased plants wilt in dry and hot conditions and may die off prematurely. Affected seedlings may die before reaching the surface and fail to emerge. Crop losses can be severe, exceeding 50% particularly in tropical and sub-tropical countries (Beshir & Degago, 1997, Kurmut *et al.*, 2002). Resistance of faba bean cultivars and land races to foot rot caused by *F. solani* has been described (Beshir & Degago, 1997) but no QTL studies have been published to date. Within a study conducted as part of the Pulse Crop Improvement Network (PC GIN) 76 *Vicia faba* accessions from collections held at NIAB and JIC were screened for seedling resistance to foot rot in a root-dip assay. Three isolates of *F. culmorum* and *F. solani* isolated from symptomatic faba bean plants collected at a field trial sites in Cambridge, UK, were included in the experiment. Severity of root and hypocotyl symptoms was scored one month after inoculation. A wide spectrum of symptom severity as observed and several accessions appeared to be highly resistant and displayed none or only small stem lesions and an intact root system while the most susceptible accessions showed completely blackened necrotic stem bases and root systems. Resistant and susceptible accessions have been crossed to create biparental mapping populations for the identification of QTLs linked to foot rot resistance. An RNA-sequencing experiment has been set up to study differential expression between susceptible and resistant accessions at several time points during development of the infection. These approaches may facilitate identification of candidate genes linked to resistance to foot rot caused by *Fusarium* spp.

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Evidence that the faba bean pathogen, *Botrytis fabae*, reproduces sexually in the UK

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ABSTRACT

Botrytis fabae is a necrotrophic fungal pathogen affecting faba bean. Faba bean is an important break crop and protein seed crop. However, *B. fabae* infections can reduce yield by 30%. Understanding the epidemiology of *B. fabae* in the UK may help inform growers on how to combat this disease more effectively.

Field surveys in other countries have shown that this pathogen is clonally reproducing. Clonal species are composed of a number of lineages, and this can reduce genetic diversity compared to sexual populations. A study of 211 UK faba bean isolates showed high levels of diversity and few clonal lineages, which is inconsistent with a purely clonal population. By genotyping a large collection of UK isolates over their mating-type (MAT) loci, this study has provided strong evidence that the UK population is sexually reproducing, establishing a 1:1 ratio in MAT 1-1 and 1-2 loci in *B. fabae*.

Greater genetic diversity derived through sexual recombination could facilitate the rate of adaptation to control strategies in *B. fabae*.

Mechanisms and resistance sources of *Pisum* spp. collection against *Uromyces pisi*

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ABSTRACT

Pea rust disease is a major disease worldwide. In temperate climates it is caused by *Uromyces pisi*, whereas in tropical areas of India it has been ascribed to *U. viciae-fabae* (Barilli *et al*., 2009*a*). Large screenings of pea germplasm for rust resistance have been described before, but only moderate levels of quantitative resistance were identified against *U. pisi* with no complete resistance or hypersensitive response detected so far (Barilli *et al*., 2009*b*).

To complement these studies, here we show the response of 320 accessions including both cultivated pea and wild relatives, inoculated with a highly virulent isolate of *U. pisi* under field and controlled condition, in addition to histological assessment to discern the underlaying resistance mechanisms. Response of adult plants under field conditions was assessed in three consecutive field seasons by recording disease severity (DS) at 30 days post inoculation (dpi). Response of inoculated seedlings was accessed under controlled conditions recording daily from on 7 to 14 dpi the number of rust pustules in a marked area, allowing calculation of latency period (LP_{50}) and area under disease progress curve (AUDPC). At 14 dpi DS, infection frequency (IF) and infection type (IT) was recorded.

From field and seedlings evaluations large variations were detected between accessions in most of the studied traits with partial resistance detected in both cases. However, no correlation was detected between variation in rust germination on the leaf surface before substomatal-vesicle formation events and the resistance to *U. pisi*. Consequently, the five more resistant, tolerant, and susceptible accessions were studied for post-appressorium events including colony size, hyphae number and haustoria number. This study identified new partially resistant pea accession that harbour a lower level of symptoms which was associated with smaller rust colonies due to a reduction in the number of haustoria and hyphal tips per colony.

These findings demonstrate that screening pea collections continues to be a necessary method in the search for complete resistance against the pathogen *U. pisi*. In addition, the great phenotypic diversity contained in the study collection will be useful for further association analysis and for breeding perspectives.

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Comparative amplicon sequencing to explore the relationship among land use history, plant health and disease management

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ABSTRACT

Peanut is an economically important oil crop worldwide, which is a nutritious source of human food and animal feed and benefits the cropping system by fixing nitrogen and enhancing crop yield. Microbial communities associated with plants are distinctive for each plant part and compared to other microenvironments, the rhizosphere is rich in microbial abundance and dynamism. Rhizosphere microbial populations are less diverse but denser than bulk soil inhabitants and can promote crop health and yield. Knowledge of the composition and biology of rhizosphere microbial communities is, therefore, key to sustainable and productive cropping system. The aim of this project was to assess the impact of microbial communities associated with soil from peanut paddocks on crop growth and health. Soil was collected from Australian peanut paddocks with four different cropping rotations: 1) 3 years continuous mono-cropping of peanut, 2) 5 years sugarcane-one season peanut, 3) 5 years sugarcane-peanut-barley-peanut, 4) No sugarcane-two years peanut, and also from a pasture. The impact of different soils on crop growth was assessed through planting peanut varieties Sutherland and Middleton as well as maize variety PAC624 into different soil samples and measuring crop growth after 6 weeks. Physicochemical properties of collected soil were measured and 16S amplicon sequencing of soil microbial communities was conducted to find out the relationship between nutrient status and composition of bacterial communities. Bacterial communities isolated from different soil samples were tested for their potential to suppress net blotch, an important fungal disease of peanut in Australia, cause by *Didimosphaeria arachidicola*. Plant growth parameters showed significant variation in response to soil samples. Furthermore, 16S metagenomics sequencing of the rhizosphere soil microbiome communities showed differences among the rotations and crops. Additionally, the linear discriminant effect size (LEfSe) analysis and network analysis uncovered the crop and rotation effect on bacterial co-occurrence structures. There were 50 significant associations among the 12 phyla uncovered in network analysis, with slightly fewer significant positive associations than negative associations (24 *vs*. 26), suggesting a potentially nonreciprocal relationship among rhizosphere soil bacteria, peanut, and maize. Three bacteria isolated from Kingaroy and Bandaberg peanut fields used in glasshouse experiments against *D. arachidicola* successfully supressed disease. Our study revealed how the pre-existing microbial communities in soil impacted plant growth and health. The use of high throughput amplicon sequencing technology revealed the type of microbial alterations occurring in the rhizosphere of peanut and corn crops, as well as in healthy and diseased peanut crops. These insights significantly improved our

knowledge of microbial communities and their interactions in soil and identified rhizosphere microorganisms that may be used to improve peanut yield and potentially manage peanut diseases in an environmentally friendly manner.

Parallel Session 4A: Physiology and Genetics

The importance of tertiary roots in young peas for future service legume selection

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ABSTRACT

Combining a legume as a service plant with a cash crop may present a double agroecological advantage: the legume may help in weed control by competing with them for light and soil elements such as nitrogen (Lorin *et al*., 2015), while improving nitrogen use efficiency of the cropping system thanks to symbiotic nitrogen fixation (Fustec *et al*., 2010). Among other legume species, pea has been shown as one of the relevant species to control weeds when intercropped with rapeseed, based on its aboveground traits (Lorin *et al*., 2015). However, legumes are known to be poorly competitive for mineral nitrogen uptake at crop establishment (Hauggaard-Nielsen *et al*., 2009). A mean to increase the value and productivity of new agroecological practices such as intercropping in a context of herbicides and chemical nitrogen fertilizers limitation, is to identify relevant levers to improve weed control using intercropping with legumes such as pea. In legumes, the ability to absorb nitrate may be linked to lateral root development (LR) (Dayoub *et al*., 2017). In this context, highly branched and fast-growing root systems would be traits of interest for a service legume (Dayoub *et al*., 2017). The formation of LRs is itself induced by the nitrate signal, but may compete with nodule formation, which also depends on soil mineral nitrogen concentration (Herrbach *et al*., 2014). In order to explore the trade-offs between the formation of LRs and the formation of nodules, we have phenotyped the root system architecture of 3-week-old pea plants (*Pisum sativum* L. 'Frisson') cultivated in greenhouse conditions under various nitrate concentrations in presence or absence of *Rhizobium leguminosarum*. As desired, contrasted root architectures were obtained through the different nitrate concentrations, impacting the nodules number ($P<10^{-13}$), biomass ratio ($P<0.01$), Specific Leaf Area index ($P<0.001$) and root diameter ($P<0.001$). Among these differentiated root systems, our results highlight the *Rhizobium* effect on the length of primary root ($P<0.03$), the length of secondary roots ($P<0.001$), and particularly on tertiary roots. Our study demonstrated that tertiary roots of the pea are more sensitive to the presence of the bacterium compared to the primary and secondary roots through several variables: roots number (60 tertiary roots per plant on average against 90 in the presence of *Rhizobium*, $P<0.01$); which is reflected in the indexes results linked to root branching (branching ratio $P<0.01$); but also on the root density: root branching architecture ($P<0.03$) and root branching intensity ($P<10^{-5}$). In conclusion, tertiary roots development must be henceforth considered as a key factor and a promising selection requirement, for an improved efficiency in weed control by a relevant service plant more suitable for the productivity of new systems, and the effectiveness of new practices such as associations crops.

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Genetic variation for seed quality traits in pea: Generating novel germplasm

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ABSTRACT

The demand for plant-based foods has increased many-fold in recent years, due largely to public concern for the health of the environment as well as human health. The need to radically transform food production systems has been emphasised by several studies, including the EAT-Lancet Commission report (Lucas & Horton, 2019). Among plant foods which can sustain us, while promoting the health of humans and the environment, legumes feature prominently as crops which additionally do not require nitrogen fertiliser. The seeds of many pulse (legume) crops provide a valuable source of protein, starch and micronutrients, but genetic improvement of the concentration, composition and bioavailability of their seed components would enhance their credentials to replace animal food products completely (Robinson *et al.*, 2019). Pulse crops such as pea can respond to the demands of plant-based food manufacture by providing protein and carbohydrate with defined quality and functional attributes. Although pea protein is being used ever more widely within the rapidly growing dairy- and meat-replacement food industries, it nonetheless presents targets for genetic improvement to meet market needs, as well as for the maintenance of good health. For example, with regard to amino acid balance, it is clear that the amino acid scores for diverse protein sources should be corrected for protein digestibility to allow accurate comparisons of protein sources, based on bioavailability (Stevenson *et al.* 2018). This is particularly relevant to the design of foods for preventing early loss of muscle protein, associated with frailty in later years.

Several reports have shown that some seed proteins in pea are either poorly digested or have anti-nutritional properties. Mutations impacting on several classes of protein have been identified, following screens of natural germplasm and mutant pea resources (Clemente *et al*., 2015; Domoney *et al*., 2013; Viegolas *et al*., 2008). These include deletion mutations where the synthesis of three classes of seed protein (albumin 2, lectin and trypsin-chymotrypsin inhibitors) negatively associated with digestibility has been abolished. The three mutations have been combined into a single genetic background, where their impact on protein digestibility (Brodkorb *et al*., 2019), amino acid composition and field performance are being assessed.

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The WHIRLY gene family in soybean (Glycine max)

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ABSTRACT

WHIRLY (WHY) proteins play critical roles in plant development and responses to biotic and abiotic stresses. The family comprises of single stranded (ss)DNA-binding proteins that associate with nucleoids in chloroplasts and mitochondria. The presence of DNA binding domain is crucial for WHY protein participation in plastid DNA damage repair (Wang *et al*., 2021). Moreover, some of the WHY members including WHY 1 and WHY 2 are located in multiple cell compartments (Grabowski *et al*., 2008; Huang *et al*., 2020). The number of WHY members differs among plant species. Many species contain only two or three members. However, an analysis of the soybean genome identified seven loci encoding WHY proteins: Glyma.01G043000, Glyma.02G019900, Glyma.18G124800, Glyma.19G249500, Glyma.02G020400, Glyma.08G297200, Glyma.03G252100. Interestingly, three of the members (Glyma.01G043000, Glyma.02G019900 and Glyma.02G020400) are lacking conserved ssDNA binding domain (ssDBD), which suggests that their functions might be different to the extensively studied WHY proteins from *Arabidopsis,* which all harbour conserved ssDBD domains. The subcellular localization of the soybean WHY proteins was determined by transient expression using WHY-GFP fusion proteins. This analysis revealed that soybean chloroplasts contain at least four WHY protein members (Glyma.01G043000, Glyma.02G019900, Glyma.18G124800, Glyma.19G249500) while two forms (Glyma.19G249500, Glyma.03G252100) were localized in the mitochondria. The *WHY* genes were differentially expressed in shoot and root tissues. Glyma.08G297200 was the most abundant transcript in shoots and roots, while the mitochondrial forms were highly expressed in nodules. The levels of Glyma.08G297200 transcripts were decreased following exposure to abiotic (dark chilling) and biotic (*Phakopsora pachyrhizi*) stresses, and were also decreased by treatment with ethylene (ET). The function of the three GmWHY lacking ssDBD are unknown but future studies will assess the functions of all WHY forms.

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Genetic variation in transpiration response to vapour pressure dificit (VPD) of two faba bean (Masterpiece & Robin Hood) cultivars using different methodologies

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ABSTRACT

Legume crops are very important for both human nutrition and agricultural productivity, as they are a primary food source in many parts of the world and an important rotational crop used to improve soil nitrogen status. Among the grain legumes, faba bean (*Vicia faba* L.) is one of the most important winter crops for human consumption in the central part of the world (e.g. Egypt, China, Ethiopia and Latin America) that can be utilized as green manure and for stock feed . Faba bean (*Vicia faba* L.) is regarded as more sensitive to soil water deficit than other grain legumes, thus water conservation traits that alter the balance between water supply and demand have gained much interest. In this context, limited transpiration under high VPD is considered one of the most important mechanisms for adaptation to water deficit conditions. In this regard, three different systems, i.e gravimetric measurements of whole plant transpiration with a single balance, infra-red gas analysis of single leaf and whole plant transpiration were tested for measuring transpiration response to VPD on the same plants to see whether the responses are consistent across different methodologies and plant tissues (i.e. whole plant *versus* single leaf). Such investigations provide an opportunity to determine possible physiological mechanisms regulating the response. Thus two British faba bean genotypes were grown in the glasshouse to measure their transpiration response to VPD with the previously mentioned systems. This study revealed some differences and consistencies in TR response to VPD over the three tested systems, with substantial genotypic differences between cultivars, Masterpiece and Robin Hood. Unlike the usual model of transpiration rate increasing linearly with increasing VPD, this study with two faba bean genotypes showed a reverse model with transpiration restricted by increasing VPD. Where, both genotypes displayed a breakpoint in their TR response to VPD, above which there was a stability or a decrease and sometimes a little increase in transpiration. While transpiration of cv. Robin Hood was clearly limited when VPD was greater than 2.2 kPa, transpiration of Masterpiece increased until 3.3 kPa and after which, transpiration was either stable or decreased over the three systems. This genetic variation suggests that much larger variability could be expected in bigger populations as well as the complex inheritance of the trait, which means more than one controlling mechanism. Transpiration responses to VPD were consistent across both controlled (individual leaf cuvette & whole plant gas exchange chamber) and un-controlled (glasshouse-based single balance) environmental conditions, and between leaf (leaf cuvette) and whole plant (whole plant gas exchange chamber and glasshouse-based single balance). The consistency of the observed responses over the three systems supports the possibility that those responses occur in fluctuating field conditions.

Session 4B: Legumes in Pasture

Mixed grass-legume sward nutritional quality improvement as a result of soil liming application

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ABSTRACT

Annual rates of agricultural lime applications to grassland in the UK have been in decline since the removal of the post-WWII liming subsidy in the 1970's. Although improved grassland only accounts for approximately 11.2% of Scotland's total land area, maintaining soil health in these areas is key to ensure optimised productivity for this agricultural sector. Optimising the soil pH by using agricultural lime is known to impact grassland productivity including the potential for yield increase and improving legume dominance within a sward. With the observed national decline in liming applications, there is also great potential for below-optimum grassland nutritional quality. The explicit investigation of the impact of poor soil pH management on grassland nutrition (yield, sward composition, N and C, crude protein, fibre) has not yet been fully researched.

Sward samples were collected in a long-term field experiment at Scotland's Rural College (SRUC), Craibstone, Aberdeen. Comprising an eight-phase cropping rotation, the experiment has been managed since 1961 to have a soil pH gradient from 4.5 to 7.5 within each row in 0.5 pH increments. Replicate quadrats were taken within each plot at each estimated grazing time from three grass-clover swards representing years one-three since their establishment in an undsersown crop of barley. The sward composition improved to include a greater proportion of clover in the overall yield both by increasing soil pH values to the optimum range (pH 6.0–6.5) and the length of time since establishment, with the more mature grassland having an elevated proportion of clover within the sward. Although the lowest pH value soils is prove to be uninhabitable for clover. Improving the soil pH values from pH 4.5–5.5 doubled the crude protein content of the sward. By not properly managing soil pH values, there is a potential for a reduction in crude protein content by 50% of mixed swards, an increase in the proportion of less digestible fibre fractions of a sward, and a reduced overall grassland yield.

Multi-species grasslands stimulate productivity and resilience of a temperate crop-grassland rotation

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ABSTRACT

Crop-grassland rotations are common in European crop-livestock systems, with either a goal of income diversification or feed autonomy for the herds. Such rotations deliver services like easier management of weeds and pests, but only few studies investigated the effect on productivity of different types of grassland.

On one hand, intensive grasslands are often based on grass monoculture, while we know that plant diversity can increase grassland productivity and reliance on regular water and fertiliser supply. On the other hand, crop yields were shown to depend highly on cover crops.

Simultaneously, climate change is rising concerns about the impact of weather disturbance on agricultural systems. If the short-term or annual effect of summer drought is well studied, the literature is poor regarding to longer-term effect of such extreme weather.

We first investigated how grassland plant diversity can improve the productivity of grasslands and increase resistance to summer drought. Using the same experiment, we established a follow-on crop to explore the effect of a former grassland community, exposed to drought or not, on the follow-on crop. To do so, we measured the crop biomass and nitrogen yield and relate it to former treatments. The crop being managed homogeneously, the only unequal factors are derived from grassland phase. Thus, we compare results from crop with different backgrounds, and so can source species, diversity or drought-induced legacy delivered from the grassland phase.

We found that grassland legume species were the most efficient in stimulating the follow-on crop yield. There was no additional mixture benefit than the average effect, contrarily to what was found in the grassland phase alone.

Crop performance was lower where grassland leys were previously stressed by a summer drought, but this effect depended on former grassland composition: some species were more resistant. Once again, no mixing effect was noted.

A grass monoculture receiving high rates of nitrogen fertiliser was introduced during the grassland phase, but was treated the same during the crop phase. Albeit fertiliser increased biomass production during the grassland phase, its long-term net effect resulted in a lower yield achieved by the follow-on crop.

We finally gathered results from the grassland phase where diverse swards were performing best, with the crop phase where yields were increasing with former legume proportion. Overall, multi-species grassland with high legume content at low input level delivered higher full rotation biomass and nitrogen yield than a rotation based on highly fertilised grass. Plant diversity also helped mitigating the impact of summer drought.

We conclude that legume inclusion in diverse swards is crucial for stimulating productivity and sustainability of temperate grassland-crop rotations.

Positive legacy effect of previous legume proportion in a ley on the performance of a following crop of *Lolium multiflorum*

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ABSTRACT

We investigated the legacy effects of a previous ley's legume proportion on the performance of a following grass crop in a rotation. At the end of a three-year diversity field experiment (Hofer *et al*., 2017; Hofer *et al*., 2016), the legume proportion of the plots ranged from 0 to 100%. In April 2015, these swards were removed using herbicide and all plots were re-seeded with a pure *Lolium multiflorum* L. crop. This sward was subsequently harvested four times over the following one-year period (three times in 2015 and once the following April 2016). The above-ground biomass and its N content were measured at each harvest. Labelled ^{15}N fertilizer (50 kg N ha^{-1}) was applied during the 2nd and 3rd re-growth periods to determine N fluxes in the system.

Across the one-year period, a clear and significant legume-legacy induced increase in biomass yield of *L. multiflorum* was observed over the entire range of previous legume proportions when compared against the non-legume ley (Non-Leg), the effect being 2.15 and 1.73 t ha^{-1} ($P \leq 0.001$ each) in swards with 50% (Leg_{50}) and 100% (Leg_{mono}) legume proportion of the previous ley, respectively, or up to +30%. The legume-legacy effect on biomass yield was most pronounced at the 1st harvest after sowing and persisted into the 2nd harvest ($P \leq 0.05$ both, over entire range of previous legume proportion), though was no longer evident at the 3rd harvest. Importantly, the legume-legacy effect returned in the 4th harvest in the second experimental year (April 2016) on almost the entire range of previous mixture legume proportions ($P \leq 0.05$). The N content of the following *L. multiflorum* was increased by up to 2.3 g kg^{-1} DM ($P \leq 0.001$) at the first harvest, though not at any of the subsequent harvests. As a result, the very same legume-legacy pattern in the following crop was observed for N yield as for biomass yield. Examining the source of N contributing to N yield confirmed that more N was derived from the soil at harvest 1 for previous legume leys (up to 53.4 kg N ha^{-1} for Leg_{50}, $P \leq 0.001$) and harvest 2 (approx. 7 kg N ha^{-1} for both Leg_{50} and Leg_{mono}, $P \leq 0.001$) compared to Non-Leg, with a significant increase still seen for legume mixtures at harvest 3 (3.9 kg N ha^{-1} for Leg_{50}, $P \leq 0.01$).

These results demonstrate a sustained soil-transferred performance-enhancing legacy effect on a following crop in a rotation, with previous legume proportions of 50% having a comparable effect compared with that of a previous legume monoculture.

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^{15}N natural abundance and ^{15}N leaf labelling methods provide similar magnitudes of nitrogen transfer from clover to associated grass

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ABSTRACT

Nitrogen (N) transfer from clover to associated grass in mixtures may present a significant, but often unaccounted contribution to symbiotically fixed clover N. The N transfer has been determined using ^{15}N labelling (LAB) and ^{15}N natural abundance (NA) methods. The impact of both methods on the resulting N transfer has not yet been assessed systematically under identical environmental and management conditions.

The aim of the study was to test (i) the comparability of the LAB and the NA method and (ii) the robustness of each method to determine the N transfer over a two-year period. For this purpose, a red clover-perennial ryegrass mixture and a pure grass stand was established on soils with different fertilisation histories in a long-term field experiment. To test the robustness of the methods, different procedures were applied for both methods. Procedures of the LAB method involved two labelling protocols. Procedures of the NA method differed in the sources of ^{15}N signatures used for plant available soil N (PASN) and clover N transferred to grass, i.e. the two sources of the grass in the mixture. To examine the effect of different ^{15}N signatures of PASN, we included soils that have received no, sole organic, or sole mineral N fertiliser for three decades.

Overall, NA and LAB resulted in a comparable proportion of about 40% of grass N transferred from clover. The NA method resulted in proportions ranging from 35% to 45% and a mean of 41% across all procedures. This range was narrower than that of the LAB method ranging from 27% to 49% and a mean of 38%, suggesting that NA was more robust than LAB. When excluding one NA procedure that differed significantly from all the others, remaining NA procedures had similar results in the close range of 41% to 45%. The ^{15}N signatures representing those of PASN and of clover N transferred to grass differed clearly, by 3.3‰ to 5.4‰ in zero and organically fertilised cropping systems, thus providing a solid basis for the application of the NA method. However, their difference was less than 2‰ in the mineral fertilised cropping system. The LAB procedures were affected by a temporally non-uniform ^{15}N enrichment of the clover root, which violates a basic assumption of the method. During two years of cultivation, 3.5 to 8.8 g m^{-2} of clover N was transferred to grass depending on the fertilisation history of the cropping system.

The NA method can be applied across a range of fertilisation treatments. A time and cost saving NA procedure to determine N transfer requires only the ^{15}N signature of the shoots from mixtures. The on average 40% of grass N transferred from clover need to be considered when determining the input of symbiotically fixed N by clover-grass mixtures.

Session 5: Legumes in Africa One

Productivity and resilience merits of legume rotations and intercrops in maize-based cropping systems of Eastern and Southern Africa

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ABSTRACT

In an environment characterized by low productivity, climate change and rampant land degradation, maize monocropping remains a common practice in East and Southern Africa (ESA). The need to shift towards conservation agriculture (CA) based sustainable agricultural intensification technologies that seek to enhance and diversify farmers from the maize monoculture practices is apparent. This paper highlights and shares some results from a few projects implemented in the last 10 years that addressed maize-legume rotations and intercrops as a regional policy priority.

Working across five countries of ESA, the SIMLESA project (Nyagumbo *et al*., 2020) showed that across all the environments and relative to conventional tillage, CA maize-legume rotations had the highest maize yield increase (35%) compared with CA continuous maize (29%) and CA-maize-legume intercrops (15%). Furthermore, the highest returns (90–95%) to CA investments by smallholder farmers were realised under low rainfall conditions (<700 mm), thereby providing clear evidence of the climate smartness of CA systems under soil moisture stressed conditions. These CA yields relative to conventional till however were subdued to 26, 19 and 15% in medium-wet (700−1300 mm) and depressed even further to +1, -18 and +9% in wet (>1300 mm) environments, for CA-rotations, CA-sole and CA-intercrops, respectively. Legume rotations and intercrops thus not only helped to diversify diets from maize but also helped to ins

In Malawi, the merits of three climate smart agriculture (CSA) technologies, namely conservation agriculture (CA), maize–pigeonpea (Maize-PP) intercrops and a local organic and inorganic soil amendment known as Mbeya fertilization (Mbeya-fert) implemented by farmers on their own, were assessed with respect to their soil quality and maize yield effects from 2018–2019 (Nyagumbo *et al*., 2021). CA and Mbeya-fert improved maize yields by 51 and 19% respectively, compared to conventional farmer practices while the intercrop system offered no apparent maize yield improvements but also supplemented the protein needs of the farmers through the pigeonpea. Yet increases in SOC compared to the conventional farmer practices amounted to 6.5, 12 and 10.5 t C ha^{-1} for CA, Mbeya-fert, and Maize-PP intercrops, respectively, thereby suggesting a higher potential for carbon sequestration from CSA technologies and in particular, maize-pigeonpea intercrops. The paper also presents other examples from Zimbabwe of maize and forage legume interactions in mixed crop-livestock systems. We conclude that the use maize legume intercrops and rotations evidently could enable farmers to be more resilient, productive and adapt better to climate change shocks leading to improved food security and livelihoods.

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Broadening farmer options through legume rotational and intercrop diversity in maize-based cropping systems of central Malawi

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ABSTRACT

Smallholder farmers across southern Africa have limited access to adequate quantities of inorganic fertilizers, and this limits crop productivity. Integration of legumes such as groundnut (*Arachis hypogaea* L.) and pigeonpea (*Cajanus cajan* L.) improve soil fertility and subsequent cereal crop productivity through biological nitrogen fixation (BNF), and high-quality residues. A 4-year, multi-site, on-farm study in Malawi evaluated diverse legume systems, quantified crop production, N accumulation in groundnut and pigeonpea and economic viability. The study was implemented at six research sites with different agricultural productivity potential based on precipitation, elevation, and temperature; to evaluate crop performance by environment. The six cropping systems evaluated were sole pigeonpea or sole groundnut rotated with maize (*Zea mays* L.) (PP-MZ and GN-MZ), groundnut/pigeonpea intercrop rotated with maize (GNPP-MZ), maize/pigeonpea intercrop (MZPP), continuous unfertilized maize (MZ-MZ), and fertilized maize (MZ+F). Total N accumulated by cropping system was in the order GNPP > PP > MZPP > GN at 180, 130, 103 and 87 kg N ha^{-1} respectively. In the groundnut/pigeonpea intercrop, despite a reduction of pigeonpea biomass, pigeonpea was still the main driver for N cycling in the systems. The average percentage of N derived from BNF (BNF-N%) from all plant components and across sites was 66% for groundnut and 52% for pigeonpea. Average maize grain yield for response years when rotated with legumes was 4.82, 3.25, and 2.16 Mg ha^{-1} for sites with high, medium, and low agricultural productivity potential, respectively. The pigeonpea-maize rotation produced the most biomass but had modest economic and agronomic returns during the legume phase. This study highlighted that, for hot and dry environments, groundnut was the most effective species at increasing maize yield in a subsequent year. The groundnut/pigeonpea-maize rotation system met multiple goals including high pigeonpea biomass, profitable groundnut grain, and high maize yields during the rotational year.

Integration of tropical legume species into smallholder conservation agriculture systems of southern Africa

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ABSTRACT

Smallholder farmers in southern Africa are faced with numerous challenges, ranging from negative impacts of a rapidly changing climate, increasing population pressure, and declining soil fertility - all affecting their food security and livelihoods. Healthy soils which maintain or increase productivity and profitability of current farming systems are therefore critical. Several technologies are in reach of smallholders and amongst them are organic and inorganic fertilizers as well as different legume species adapted to the agro-ecological conditions of southern Africa. Conservation Agriculture (CA) systems have been tried in this region for the last 30 years with varying success. One of its key principles, besides minimum soil disturbance and crop residue retention, is crop diversification through crop rotation or intercropping. This provides an opportunity to integrate tropical legume species into the predominantly maize-based farming systems, either as grain legumes or as green manure cover crops. However, land constraints and lack of formal markets for seed and produce have only gradually increased legume use in the last decades despite their proven benefits. Farmers have a clear preference towards grain legumes with multi-purpose use that can also be sold on semi-developed markets. Green manures on the other hand will only become attractive if linked to the livestock value chain as soil fertility improvements, emanating from integration of green manures, do not seem attractive enough to warrant larger adoption. Several strategies (e.g. rotation, intercropping, double cropping and relay cropping) to integrate legumes have been tried in recent years and intercropping systems that minimize competition between maize and the associated legumes show great promise. These systems do not only improve productivity but also profitability, nutrition and dietary diversity, fodder and fuel production under a changing climate. Greater promotional efforts and support to an enabling environment are required to increase greater uptake of legumes and their impact at scale in the near future.

Using functional traits to inform selection of multipurpose legumes for African smallholders

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ABSTRACT

Legumes show considerable diversity in form and function and can contribute multiple benefits to smallholder farmers: food, income, feed for livestock, fertility for following crops, protection of soils from erosion and so on. The LegumeSELECT project addresses a major question that underpins the adoption of multi-purpose legumes in Sub-Saharan Africa (SSA): which legumes perform best and deliver the benefits farmers demand, under which conditions and management, for improved smallholder productivity? To this end we are enhancing a prototype decision support framework, the LegumeCHOICE tool, by embedding trait-based understanding of legume functions into the tool's decision typology. We hypothesize that differences in performance including the outcomes of root-soil interactions can be explained by differences in legume biochemical and architectural traits. In controlled condition experiments, we are combining non-destructive X-ray Computed Tomography (CT) imagery with stable isotope labelling approaches to establish the quantitative importance and mechanisms of legume contributions to soil C and N stocks and nutrient supply. X-ray CT is enabling the characterisation of root architectural traits and to observe differences in soil structural development. Continuous ^{13}C-CO_2 labelling is enabling quantification of the contributions of plant-derived C to soil C-pools and the impact of roots (mediated by soil microbial communities) on mineralization of soil organic matter. Our goal in these experiments is to establish trait-soil relationships that predict legume performance, contributing to the objective selection of legumes towards the sustainable intensification of agriculture in sub-Saharan Agriculture.

Biogenic amines in African locust bean (*Parkia biglobosa*) fermented seeds

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ABSTRACT

African locust bean (*Parkia biglobosa*) is a legume widely spread in west Africa. The major consumed part is the seeds after processing in the so-called Soumbala in Ivory Coast. It is rich in proteins and lipids and used as a condiment to enhance sauce flavour. The seeds processing can be generalized as a first cooking to allow the dehulling of the seeds, a second cooking of the almond, an alkaline spontaneous fermentation of 2–3 days before final sun-drying. During fermentation, microorganisms belonging to the genus *Bacillus* are responsible of an extensive proteolysis (Odunfa et Adewuyi, 1985) and lipolysis (Ouoba *et al*., 2003). This gives the specific flavour to the product but may lead to toxic compounds such as biogenic amines. Biogenic amines accumulate by microbial decarboxylation of free amino acids and are thus susceptible to be present in fermented protein rich foods. They were reported in wine, cheese and fermented fish while they have not been studied yet in processed African locust bean seeds. The objective is to evaluate amino acids decarboxylation activities of *Bacillus* spp. isolates from Soumbala and biogenic amines content.

Soumbala samples were collected among six producers in three regions of Ivory Coast. 52 *Bacillus* spp. strains were isolated and identified using API 50 CHB kits. Histidine, lysine, arginine, phenylalanine and ornithine decarboxylation activities and arginine dehydrogenase activities were determined in order to study their ability to produce histamine, cadaverine, phenylethylamine and putrescine. Soumbala samples were analysed for histamine, cadaverine, phenylethylamine and putrescine content.

Bacillus spp. strains were identified as followed: *B. subtilis* (16); *B. lentus* (3), *B. pumilus* (1), *Geobacillus stearothermophillus* (5), *B. megaterium* (9), *B. firmus* (2), *B. circulans* (2), *Brevibacillus* non reactive (5), *B. licheniformis* (4), *Aneurinibacillus aneuriniliticus* (4), *B. cereus* (1). 16 strains did not show arginine deshydrogenase activities and histidine, lysine, ornithine, or phenylalanine decarboxylation activities. Biogenic amines content of Soumbala was in average 82 mg kg^{-1} for histamine, 36 mg.kg^{-1} for cadaverine, 45 mg kg^{-1} for putrescine and 272 mg kg^{-1} for phenylethylamine, some samples reaching high levels. Strategies for the control of biogenic amines production in African locust bean fermented seeds are discussed.

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Recorded short talks to introduce Poster Presentations

6–10

Poster 6
Management of rust in faba bean by crop diversification

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ABSTRACT

Faba bean plays a key role in sustainable agriculture, given its ability to fix nitrogen. Rust is one of the most important diseases affecting faba bean. It is caused by the biotrophic fungus *Uromyces viciae-fabae*, whose windborn spores infect all aerial parts of the plant. The high economic and environmental cost of fungicides, and the scarcity of resistant cultivars adapted to the different agronomic situations make necessary to find alternatives for rust control. Crop diversification has been proposed as a sound option for disease management (Boudreau, 2013). We studied the potential for rust management in faba bean intercrops and in cultivar mixtures. First, we carried out four intercropping field trials across 3 years in two locations each one consisting of faba bean intercropped at 50% proportion either with wheat, barley or pea, in an alternate replacement system. Second, we performed four cultivar mixture field trials in which a resistant and a susceptible faba bean cultivars were mixed at different proportions (0–100, 25–75, 50–50, 75–25 and 100–0).

A significant reduction of rust infection was recorded on faba bean when intercropped with barley but not when intercropped with wheat or with pea. Rust was also significantly reduced in cultivar mixtures, the reduction increasing with the proportion of the resistant cultivar in the mixture.

Based on these results, additional experiments were performed on faba bean intercropped with barley seedlings inoculated under controlled conditions. Results confirmed rust reduction and suggested a barrier effect by barley as an important mechanism explaining that reduction. To further investigate the mechanisms behind disease reduction the combined effects of intercropping and nitrogen fertilization on rust disease will be assessed by experiments under controlled conditions.

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Poster 7
Physiologiocal and symbiotic behavior of N_2- fixing common bean subjected to iron deficiency: A functional dissection

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ABSTRACT

Iron is an essential micronutrient for plants as well as other organisms. Plants take up iron from the soil in which its solubility is extremely low especially under aerobic conditions at high-pH range. Functioning in various physiological and biochemical processes such as, photosynthesis, respiration, DNA synthesis and N2 fixation. In the legume–rhizobia symbiosis, Fe is required for nodule bacteria survival and multiplication, as well as host–plant growth, nodule initiation, development and function (Krouma *et al*., 2006, 2008). In particular, Fe is required for some key proteins like nitrogenase which represents ca. 10% of total protein in bacterial cells, leghaemoglobin which represents ca. 20% of total protein in infected plant cells, and catalase and peroxidase which are involved in the protection of nodule components against oxidative stress. Nevertheless, differences among species and genotypes in plant response to Fe deficiency have been reported (Krouma *et al*., 2006, 2008).

In order to express the physiological basis of the tolerance/ sensitivity of some common bean genotypes to iron deficiency when depending on symbiotic nitrogen fixation, a greenhouse experiment was conducted hydroponically on two *phaseolus vulgaris* L. genotypes (ARA14 and coco banc) inoculated with an efficient strain of *Rhizobium tropici* CIAT899. Whole plant and nodule growth, leghaemoglobin accumulation, symbiotic nitrogen fixation and Fe nutrition were evaluated and the necessary correlations are established. Obtained results demonstrated a clear difference in the response of common bean genotypes to iron deficiency. ARA14 proved to be tolerant, as compared to coco blanc, sensitive. other its capacity to allocate more Fe to nodules, this genotype uses efficiently this micronutrient for nodule growth, leghaemoglobin accumulation and symbiotic nitrogen fixation. These functions can guarantee a better whole plant development because its close dependence on symbiotic nitrogen for N nutrition.

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Poster 7
Is the regulation of nodulation conserved between species at the cell type level?

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ABSTRACT

Nodules and their nitrogen-fixing rhizobia inhabitants allow nitrogen in the soil to be more accessible to plants, enabling enhanced growth. Nodulation involves co-ordination across the root cortex, epidermis and pericycle. By generating *Medicago truncatula* plants with tissue-specific fluorescent expression to be used in cell sorting then transcriptomics, the underlying nodulation mechanisms can be studied. However, bridging the gap between legumes and other crop plants that do not possess these traits is important to bring the power of nodules to non-legumes.

Whilst nodulation is generally limited to legumes, a non-legume tropical tree found on the slopes of volcanic hills, *Parasponia andersonii,* also nodulates. Thus, *P. andersonii* provides an exceptional opportunity to study both the molecular components and evolution of nodulation. Recent evidence shows that nodulation regulatory genes in *P. andersonii* are highly conserved with those in model legumes such as *M. truncatula* (van Velzen *et al*., 2018), suggesting that the genetic mechanism as well as regulation of nodulation is conserved. In fact, 290 putative orthologs have been found through a transcriptome comparison between *P. andersonii* and *M. truncatula* that show nodule-enhanced expression in both (Wardhani *et al*., 2019).

Genes that are differentially regulated at the cell type level will be compared between *P. andersonii* and *M. truncatula*. Focus is initially on several regulators that are conserved at the genomic level between *P. andersonii* and *M. truncatula*, including *NIN*, *NSP2*, *NSP1* and *ENOD11*, and the genes that they are co-regulated with. Determining the level of conservation of function and expression pattern will be crucial in evaluating the evolution of nodulation in legumes and non-legumes.

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Poster 8
Identifying the research gaps in cereal-grain legume intercropping

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ABSTRACT

Environmental stressors including rapid declines in crop pollinators and predators, intense periods of drought and flood, elevated greenhouse gas emissions and global temperature are an ever-increasing threat to efficient agricultural production and food security while agricultural intensification endangers soil health, fertility and agrobiodiversity. Intercropping (IC) cereal crops such as wheat, barley, triticale and maize with legumes including field bean, pea, lentil and lupin offers an agroecological solution to improve sustainability and environmental impacts while contributing to Net Zero targets. IC is growing two or more species simultaneously on a piece of land to maximise land use and biological resource potential. Europe is currently a net importer of protein for human and animal supply chains and recent research on IC cereal-grain legumes, carried out as part of the ReMIX project, has shown the potential for IC to meet increasing market demand for regional protein and improve farm efficiency by reducing inputs such as agrochemicals. Results confirm stabilised yields in organic agriculture and reduced synthetic input use in conventional agriculture. Compared to their respective monocultures, IC improved cereal grain quality and protein concentration in unfertilised crops secondary to enhanced rates of atmospheric nitrogen fixation (Bedoussac *et al*., 2015). Greater utilisation of resources enabled IC advantages to extend to weed, pest and disease management with trials showing disease could be reduced by up to 40% compared to sole crops (Hauggaard-Nielsen *et al*., 2007). The purpose of this research which was based on literature was to explore the focus of the work that has been carried out in Europe on intercrops, and the linkages between the research topics and the research groups.

A literature search was carried out based on keywords and carried out in Scopus. The search was constrained to European countries. Connections between keywords and groups of researchers were explored using the VOSViewer, a bibliometric analysis tool. This will help identify areas which warrant further IC research.

The analysis highlighted greater understanding of crop production and cultivation methods are required including basic agronomy to provide technical notes to farmers. This includes establishment using minimum tillage methods, optimal seed rates and varieties. Harvest methods, processing facilities and market demand for intercrops harvested simultaneously are still in their infancy. The method of action within specific plant-plant interactions, crop combinations for optimal nutrient translocation, thermal and hydrological resource use, increased opportunities for pollinators and weed and pest control are not well established. It is vital that changes in above and below ground biodiversity should be included in future research.

Acknowledgement

The authors acknowledge support from European Union through the project H2020 ReMIX (Redesigning European cropping systems based on species mixtures, https://www.remixintercrops.eu/), and the Scottish Government Strategic Research Fund.

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Poster 9

UK-grown potato bean (*Apios americana Medik*): Potential for diet biodiversification and revalorisation as well as suitability for larger scale production

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ABSTRACT

Apios americana (Medik), a native American legume from the *Fabaceae* family, is a perennial vine that bears edible tubers and beans. Analysis of *A. americana* sourced from three UK sites; South (51.4690 °N, 1.1150 °W) and North (55.9661 °N, 3.2063 °W; 57.1497° N, 2.0943° W) showed that the tubers were rich in protein (between 15 and 17%) being a complete source of amino acids, high in fibre (total non-starch polysaccharides on average 10%) and a good source of micronutrients such as potassium, phosphorus, magnesium, calcium, manganese, iron, zinc. Further comprehensive analysis of the tubers showed that the bioactive isoflavone; genistein was the major phytophenol (259 ± 12.2 mg Kg^{-1} and 356 ± 29.9 mg Kg^{-1} for the Southern and Northern tubers respectively), with the peel having a similar phytochemical profiles. Analysis additionally revealed potential opportunities for further agricultural co-products; the leaves and rhizomes in terms of recovering their macronutrients and bioactives for further food applications or feedstock.

Cultivation of *A. americana* as a high-protein staple-crop has enormous potential in Northern European countries for human nutrition, diet diversification, and for integration into the diets of various types of livestock. A number of accessions are currently under investigation in the UK, with the aim being to target those with traits which appear to have the greatest agronomic and end-use potential to aid development of the crop on a larger scale for UK climate and soil conditions. This paper will explore some of these options.

Poster 10
Maximisation of production of intercropping pea/cereal crops

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ABSTRACT

Intercropping of cereals and legumes is regarded as a sustainable production system and are likely to results in higher levels of productivity than the counterpart sole crops. However, the choices the famer makes about the management of the intercrop will affect both its productivity and the relative contribution of each crop. The management decisions will be influenced by whether the farmer is growing the crop for grain, either for human or livestock consumption, or for silage. As well as what varieties should be sown, the farmer must make decisions on the relative quantities of the legume and cereal that are sown, and the quantity of nitrogen applied. A review of experiment relevant to European agriculture has been carried out on pea/cereal intercrops to assess the effect of the sowing ratio and the nitrogen application rates on crop productivity of cereal.

The relative proportion of the pea in the yield for cereal pea intercrops is likely to be lower than the proportion of pea sown, although this will be affected by other management factors, soils and climatic conditions. Changing the seed rate from the 100% sown as a sole crop has no impact on the total yield for oats, however sowing extremely high rates of seeds in barley pea mixtures does increase the absolute yield

Applying nitrogen to pea cereal mixtures will reduce the rate of nitrogen fixation by the legume, which will in turn make the legume less competitive. The impact of applying low (less than 50 kg N ha^{-1} yr^{-1}), medium (50–100 kg N ha^{-1} yr^{-1}) or high (> 100 ha^{-1} yr^{-1}) was assessed relative to no nitrogen applied. At low rates, there was a possibility that yields could be reduced or showed little change from those receiving no nitrogen. At medium rates, yields tended to increase by between 5–35%. There were few observations where high rates of nitrogen had been applied, but the impact on yields varied between 5–15% increase to a 45–55% increase. However, unsurprisingly as the rate of N applied increase, the proportion of the legume in the yield decreased.

Acknowledgements

The authors acknowledge support from European Union through the project H2020 ReMIX (Redesigning European cropping systems based on species mixtures, https://www.remixintercrops.eu/), and the Scottish Government Strategic Research Fund.

Session 6: Legumes in Africa Two

The Legacy of N2Africa: Putting nitrogen fixation to work for smallholder farmers in Africa

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ABSTRACT

N2Africa*: "Putting Nitrogen Fixation to Work for Smallholder Farmers in Africa"* (http://www.n2africa.org/) was a large development-to-research project which ran for ten years from 2009–2019. N2Africa worked across 11 countries in East and Central, West and southern Africa through a wide range of partnerships with research and development organisations. We focused on tapping expertise from all around the world to ensure the best technologies find their way into the hands of smallholder farmers in Africa. N2Africa reached more than 650,000 farmers and the major output of the project was enhanced productivity, nitrogen fixation and production of the major grain legumes: common bean, groundnut, cowpea, soyabean, chickpea and faba bean.

Grain legumes allow a form of sustainable intensification through diversification of the farming system. They have multiple benefits – of nutritious food for the family diet, a source of income particularly for women, and improved soil fertility that boosts the yields of subsequent crops. Our approach was to target nitrogen fixation technologies to 'socioecological niches' within the wide diversity of countries and agroecologies and farming systems in Africa. A key technology introduced and promoted was the use of rhizobium inoculants which were highly successful in increasing yield of the major grain legumes and very popular with farmers due to their low cost (Vanlauwe *et al*., 2019). As we scaled out nitrogen fixation technologies we continually learn more about the problems faced by smallholder farmers. In particular, critical deficiencies of phosphorus was prevalent and needed to be addressed through judicious use of P fertilizers. What we heard repeatedly from farmers across the continent was: "*Don't come back with more demonstrations – please help us to get access to the seed and inputs!".* The 'Story of N2Africa' is available as an ebook (Giller & Ronner, 2018) and an online magazine (https://magazines.wur.nl/n2africa/welcome/.

In this talk I will elaborate on the major issues that need to be addressed to ensure that the benefits of N2-fixation can be realized by smallholder farmers in Africa.

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Rhizobial N_2-fixing efficiency is the elicitor of micronutrient accumulation in symbiotic African legumes

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ABSTRACT

The reduction of atmospheric N_2 into ammonia by the enzyme nitrogenase in bacteroids of root nodules is the process that supplies N to support growth of both microsymbiont and the legume partner. Thus, high N_2 fixation in legumes is known to correlate with greater plant growth and grain yield. Nodulated legumes supplied with exogenous mineral nutrients also generally increase their growth and mineral accumulation when compared with their non-symbiotic counterparts. Field measurements of N_2 fixation in grain legumes grown in Africa similarly revealed a relationship between N_2 fixation in root nodules and trace element uptake and accumulation in plant organs. More specifically, the high N_2-fixers under field conditions were found to accumulate more trace elements (e.g. Fe, Zn, Cu, Mn and B) in their leaves and grain than the low N_2-fixers. This suggested a relationship between the level of symbiotic functioning and mineral accumulation in the legumes studied. Furthermore, there was many-fold greater accumulation of micronutrients in the leaves compared to the grain, an indication of a higher nutritional value of the leaves (if they are edible) compared to the dry grain.

To understand this phenomen, glasshouse experiments were conducted under aseptic conditions using surface-sterilsed seeds of cowpea and Bambara groudnut that were inoculated with different rhizobial isolates, grown in sterile sand culture, and irrigated with sterile N-free Hoagland nutrient solution. At harvest, the seedlings were separated into roots, nodules and shoots. The fresh nodules were counted and weighed, while the shoots were oven-dried (60^{o}C for 72 h), weighed, and ground into fine powder (0.45 mm) for analysis of N, Fe, Zn, Cu, Mn and B. The results showed that the rhizobial isolates nodulating cowpea and Bambara groundnut differed in symbiotic performance. Of the seven rhizobial strains tested on cowpea, isolate TUT53b2vu produced significantly greater nodule number, nodule fresh weight, shoot dry matter and amount of N-fixed per plant, followed by TUT33b4vu. The concentrations of Fe, Zn, Cu, Mn and B in cowpea shoots were also markedly higher in plants nodulated by TUT53b2vu, the strain with the highest N_2-fixing efficiency. Isolate TUT33b4vu, which was the second highest in symbiotic efficacy after TUT53b2vu, similarly produced the next greater levels of Fe, Zn, Cu, Mn and B in cowpea shoots.

The data for Bambara groundnut were similar in trend to cowpea. Isolates TUTMalF1.2 and TUTMalF1.1b produced significantly greater N-fixed per plant, and generally accumulated higher levels of Fe, Zn, Cu, Mn and B in Bambara groundnut shoots.

Taken together, strain symbiotic efficiency in this study was directly linked to mineral accumulation in the two African legumes. Selecting strain/host plant combinations for symbiotic efficiency can thus increase leaf and grain quality for human nutrition/health, as well as for soil fertility.

Panacea: Pathogenomics for enhancing food security in East Africa

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ABSTRACT

Angular leaf spot (ALS) caused by the ascomycete fungus *Pseudocercospora griseola* (Crous *et al*., 2006), is a serious foliar pathogen of common bean in East Africa causing major reductions in yield and seed quality. Genetic resistance is the principal disease management tool available to grower's subsistence and small-holders against ALS. Despite lacking any apparent perfect state, *P. griseola* is observed to be genetically diverse, with heterogeneity reported within and between growing regions and distinct races (Ddamilura *et al*., 2014; Pastor-Corrales *et al*., 1998). This creates a challenge for deploying varieties with effective forms of resistance at local and regional scales. In an effort to improve understanding of how pathogen diversity and distribution impact on controlling disease,

The GCRF funded Panacea project has created new, novel biological resources and genomics tools for monitoring ALS populations in Uganda. A collection of more than 200 individuals have been isolated from infected leaves and pods on plants from the six of the major common bean production regions during concurrent rainy seasons in 2018–2019. We have constructed a *de novo* genome assembly for a single reference ALS isolate and subsequently re-sequenced a further 70 isolates to enable identification of Single Nucleotide Polymorphisms (SNPs) in order to facilitate phylogenetic analysis and to attempt to identify genetic differences that are associated with different virulence profiles.

Classical pathotyping utilising an established differential set of 12 common bean varieties (Pastor-Corrales *et al*., 1998) has been used to distinguish between different key races of ALS and statistical analyses comparing SNP diversity in the re-sequenced isolates are now being implemented in an attempt to identify genetic markers linked to race-differences. Aspects of ALS population diversity will be discussed, as will the longer term implications of establishing pathogen genomics based surveillance and monitoring resources to support sustainable agriculture in Uganda.

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Closing the yield gaps of Ethiopian faba bean (*Vicia faba* L.) and common bean (*Phaseolus vulgaris* L.)

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ABSTRACT

In Ethiopia, grain legumes are grown on 13% of the total grain crop production area and produce 10% of the yield. They provide nutritional security, sources of income for smallholder farmers and export commodities for the country. Farmers grow them either as a pure stand or in mixtures with other crops, with important roles in crop rotations. Faba bean and common bean are the two most important legumes, representing 33% and 17% of grain legume production in the country during the last decade. Since the start of crop breeding in Ethiopia in the 1960s, 34 improved cultivars of faba bean and 68 of common bean have been released, leading to huge improvements in crop productivity. Faba bean grain yield on smallholder farms has increased an average of 80 kg ha^{-1} over 10 years, and that of common bean by 60 kg ha^{-1}, but yields are still much lower than they could be. The components of the yield gap may be shown as follows: for faba bean, the average yield of a smallholder plot is 1.9 t ha^{-1}, whereas on-farm demonstration plots can yield 3.1 t ha^{-1} and experimental stations up to 4.1 t ha^{-1}. Similarly, the smallholder gets 1.5 t ha^{-1} of common bean, the on-farm demonstration plot 2.4 t ha^{-1} and the research station 2.9 t ha^{-1}. The best cultivars deliver a further 20% yield increase on these figures. There are many contributors to these yield gaps. The first step from average yield to demonstration-plot yield is attributable to improved agronomic practices that are accessible to smallholders. The second step to experimental-station yields probably requires greater investment in infrastructure for overcoming some of the biotic and abiotic stresses. Continued usage of unimproved landraces may be due partly to the cost of seed of improved cultivars and partly to eating quality and other culturally important aspects of the crops not prioritized in breeding programmes that focus on yield and stress resistance. Farmer participatory research in the Horizon2020 project "InnoFoodAfrica" will help to dissect these components of the yield gap and to indicate potential pathways to solving them.

Key words: Faba bean, common bean, yield gap, Ethiopia

Development of marama bean (*Tylosema esculentum*), an orphan legume, as a crop

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ABSTRACT

Many plant species have been consumed for a longtime by mankind, but they do not have a prominent place in organized agriculture and farming systems. These under-utilized (often referred to as orphan or neglected) crop species have been cultivated, albeit usually without much improvement. Recent efforts in the improvement of such potentially useful plant species into formal intensive agriculture practice have included detailed molecular characterization. *Tylosema esculentum* (marama bean) is unusual in this group of under-utilized species. In spite of its consumption for its oils and proteins, as well as the identification of other potentially useful products from the seeds and tubers, it has not been grown as a crop, but only collected from wild stands. It grows under inhospitable environments, particularly hot arid conditions, and, if domesticated, could be grown in environments where there are no high yielding alternatives. All steps necessary to bring this plant with such interesting characteristics into a formal crop setting, i.e. domesticating it, needs, therefore, to be carried out with urgency in light of a changing climate. These steps include identifying the added value for farmers growing this plant, the acceptability as a food and its possible industrial use, the development and distribution of improved seed and the recruitment of farmers to start growing this plant as a crop. An existing international collaboration has focused on the molecular characterization of this species with a view to identify improved types more suitable for agricultural adoption. Activities have so far included collecting a diverse germplasm, developing a whole genome sequence assembly of one individual and collecting material for identifying possible self-incompatibility genes. The sequence data has been already used to assemble the chloroplast genome which has identified a high level of chloroplast heteroplasmy in marama bean. Farmers in Namibia have also been recruited to multiply seeds which are currently being distributed to other arid regions of the world for testing the usefulness and acceptability of this crop as we develop its yield. In addition to the benefits of the domestication of marama bean, the unusual and potentially useful characteristics of this plant could ultimately greatly enhance other species needed to provide adequate nutrition to about 35% of the world population living in semi-arid to arid regions of the developing world.

Evolution of biochemical and nutritional compounds of African locust bean (*Parkia biglobosa*) seeds during their transformation in "Soumbala" in Côte d'Ivoire

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ABSTRACT

Soumbala is an African culinary product obtained from the fermentation of African locust bean seeds (ALBS) (*Parkia biglobosa*). It is a protein-rich condiment used by poor families in Africa as a substitute for fish and meat during times of food shortage. The objective of this study was to determine the impact of the three specific technological processes for the production of Soumbala identified in Côte d'Ivoire, on the different biochemical and nutritional constituents of the final fermented and dried seeds.

The three processes are typical from three regions, namely, Khorogo, Boudiali and Kouto and consist in spontaneous fermentation followed by a stabilization by sun-drying (Khorogo), steam treatment and sun-drying (Boudiali) and drying on embers (Kouto). Three samples of initial seeds (assumed the same for the three regions) and 10 final soumbala products per region were collected. Analysis consisted in macro-nutrients of interest (protein and fat content and profile, minerals) but also some compounds produced by micro-organisms during fermentation, free amino acids, and biogenic amines.

Results showed that moisture content of raw seeds was 9.4 ± 0,7 g $100g^{-1}$ (WB). Their dry matter was mainly composed by proteins (41.3±0.1), carbohydrates (26.5±0.3), lipids (23.5±0.3) and ash (4.2±0.1) g $100g^{-1}$ (WB). Their initial content in iron and zinc was 65.0±8.0 and 36.2±6.5 mg kg^{-1} and in calcium and magnesium was 0.38±0.04 and 0.43±0.01 g $100g^{-1}$. Composition of final fermented-dried seeds was even more interesting: Indeed, except magnesium, all minerals increased because of ash addition as fermentation adjuvant. In addition, proteins and lipid content increased (40.1 to 43.5 and 39.1 to 40.8 respectively). This is explained by a preferential consumption of carbohydrates during fermentation that results in increase of protein and lipid proportions. Lipid composition in fatty acids was constant throughout the process. The fatty acids by order of importance were linoleic, oleic, stearic, behenic, palmitic, arachidic, lignoceric, linolenic, eicosanoic and erucic. The main amino acids constituting proteins were glutamic and aspactic acids but they also contained a high quantity on essential amino acids by order of importance: leucine, lysine, valine, phenylalanine, isoleucine, histidine, and

threonine. However, increase of free amino acids issues from micro-organism metabolism (2% in raw seeds vs 20% in fermented soumbala) may be the cause of high biogenic amines content found is some samples. The majoritary was β-phenyletylamin with contents from 50.1 up to 203.9 ± 37.2 mg kg^{-1}. The post fermentation drying steps (sun-drying, steam treatment and sun drying or drying on embers) had no significant impact on the final product composition.

Raw and fermented ALBS are an interesting food product with a balanced composition in protein, lipids and carbohydrates and high content in minerals. Production of fermented ALBS should benefit a better comprehension and control to optimize its properties while decreasing its content in undesirable compounds such as peculiar biogenic amines.

Session 7: Ecosystem services and Intercropping

Biomass accumulation dynamic in soybean-based intercrops: Effects of species choice and spatial arrangement

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ABSTRACT

Soybean is gaining attention from farmer to meet the demand for locally produced plant proteins. Intercropping can be a way to increase production and obtain services from crops, such as weed regulation. To obtain soybean grain production and weed regulation services, one must carefully consider the choice of the specie to intercrop with soybean as one crop highly competitive against weeds may also be too competitive towards soybean. Spatial arrangement may be an option to modulate competition between intercrop components while maintaining a certain level of weed control. Thus, studying soybean and weed biomass accumulation dynamics could help identify species choice and spatial arrangement of intercrops effects on both soybean grain production and weed regulation services.

A 2 year analytical experiment was set up near Angers, France to compare the influence of two different species intercropped with soybean in substitutive design (50:50): sorghum and buckwheat; and two spatial arrangements of the intercrops: alternate rows intercropping (AR) with both crops in separate rows and within row intercropping (WR), with both crops mixed within the same row. All combinations of factors were repeated in three and four randomised complete blocs in 2018 and 2019, respectively.

Crops and weed biomass were sampled at soybean development stages V2, V4, R1, R3 and R8 (Fehr & Caviness, 1977). Growth rates (GR) were calculated between each sampling date on the basis of growing degree days.

Soybean grain yield was significantly higher for sorghum-soybean intercrop than for buckwheat-soybean intercrop with, respectively, 1.05(±0.59) and 0.70(±0.40) t/ha. Regardless the specie, soybean intercropped in AR produced significantly more grain than in WR, with a difference of 0.44t ha^{-1}. No significant differences were found between treatments for weed dry matter at harvest with an overall average of 1.68 (±1.05) t ha^{-1}.

Analysis showed that between V2 and V4, $GR_{V2\text{-}V4}$ of soybean intercropped with buckwheat within row was significantly lower than that of soybean in the other three intercrops. $GR_{V4\text{-}R1}$ was significantly affected by specie, with soybean intercropped with buckwheat showing lower growth rates than soybean intercropped with sorghum. Then, for $GR_{R1\text{-}R3}$ there was a significant effect of both specie and spatial arrangement, with sorghum and AR having a higher GR than buckwheat and WR respectively.

These results suggest that for similar weed control level of intercrops, soybean growth is affected in different ways depending on specie and spatial arrangement. Buckwheat, having a fast, early growth period ($GR_{V2\text{-}V4}$= 0.55 g m².°J) affects more

quickly soybean than sorghum (GR_{V2-V4}= 0.32 g m².°J). Also, spatial separation of component crops in AR seems to delay the effect of competition on soybean biomass, representing a potential management option for competition management in intercrops. Further analysis of light interception at the beginning of the crop cycle and nitrogen accumulation should help understand the relations between component crops and their competitiveness against weeds.

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Choosing legume as service plant for intercropping with rapeseed based on plant-plant and plant-soil interactions

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ABSTRACT

Rapeseed intercropping with frost sensitive service plants (legumes or legume-based mixtures) have recently known a fast increase in Switzerland. The introduction of such mixtures in cropping systems could help to enhance ecosystem services such as pest regulation and nutrient cycling that may be a way to reduce the use of chemical inputs. However, some gap of knowledge remains in terms of belowground traits like root-soil interactions. Comparing different legume species together and with reference crops is needed to better understand processes leading the different ecosystem services provided by legumes. The purpose of the present study is to focus specifically on plant soil interactions including legumes and their consequences on niche complementarity or facilitation processes affecting the associated cash crop.

A first greenhouse experiment aimed to compare 10 species of legumes in order to assess their capacity to enhance soil microbial activity. Then faba bean and grass pea were selected for their contrasted soil microbial activity and morphological traits in a second experiment. Six mixtures of different combinations of these two legumes intercropped with rapeseed were studied in mesocosms. At harvest, root and shoot biomasses and nitrogen contents were measured. The soil adherent to the roots and the bulk soil were sampled for microbial respiration analysis.

Response among legumes was diversified with faba bean having the highest ability to increase microbial activity compared to the others. Consequences of such properties on facilitation processes into the rhizosphere were not observed in intercropping treatments, as no significant increase of microbial respiration was shown. However, legumes influenced positively rapeseed biomass and nitrogen content, due to a weaker interspecific competition. Niche complementarity can explain legume benefits related to N_2 fixation which varied between legumes. Indeed, grass pea had less ability to fix N than faba bean when grown with rapeseed or in pure stand. These results are consistent with the fact that faba bean biomass was less sensitive than grass pea to competition with rapeseed. These first results highlighted different behaviours of two legumes when intercropped and questioned on the complementarity of legumes for the benefit of the cash crop. More investigations are needed to precise the processes involved to support field choices with time.

Assessing the contribution of legume inclusion in crop rotations to soil health and ecosystem services: A case study from UK field trials

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ABSTRACT

Grain legumes are currently subject to increasing interest as a potentially viable dietary alternative to livestock-derived protein. This is in part due to the contribution of the livestock industry to greenhouse gas production. There is a large body of previous work concerned with the contribution of grain legumes to soil fertility through increased biological nitrogen fixation, and the utilisation of grain legumes as part of a crop rotation has been shown to increase the yields of subsequent crops in the rotation. This has been particularly well explored in organic farming systems, however the uptake of grain legume cultivation in conventional farms in the UK (and much of northern Europe) has been low. Utilising long term field trials which are representative of a broad range of farming systems, we investigated how the inclusion of grain legumes in both conventionally and organically managed farming systems impacted the ability of the underlying soils to contribute to ecosystem services. Four conventionally managed rotations, all of which included spring peas in their cropping sequence, were included in the analysis. Each conventionally managed rotation received different organic amendment additions. One was untreated while the other three received green waste compost, turkey manure and paper crumble respectively. Two organic rotations were also considered. One rotation included fava beans in the cropping sequence and a one year grass and red clover green manure, and the other rotation had no grain legumes included, but did have a longer 3 year grass and white clover ley grazed by sheep. A mixture of soil chemical, physical and biological assessments were made including measurements of pH, soil macronutrient content as well as soil organic matter, potentially mineralizable nitrogen, macroporosity, water retention and bulk density. Field measures included VESS scores, earthworm counts and penetration resistance. This range of field and laboratory measurements were used to assess soil health at all stages of the rotation preceding and following legume inclusion. We were therefore able to study the interaction between differing management systems and legume cultivation, and the bearing this had on the ability of the underlying soils to provide ecosystem services. Preliminary results were interesting considering the differences in legume cultivation, inputs and ley periods. Soil organic matter was significantly higher in both organic rotations, however potentially mineralizable nitrogen was higher in all conventionally managed rotations. The organic rotations had higher VESS scores, with no difference between conventional organic amendment additions. Initial chemical results showed no change in soil phosphorus content between any of the rotations, while soil potassium was higher in the conventionally managed rotations.

Multispecies for multiple functions: Combining four grass and legume species enhances multifunctionality of sown grassland

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ABSTRACT

Assessing the role of community composition for the overall performance of ecosystems requires a quantitative evaluation of multifunctionality. We investigated plant species diversity effects on individual functions and overall multifunctionality in a three-year experiment on sown grassland with four monocultures and 17 differently composed mixtures comprising four key grass and legume species: *Lolium perenne*, *Dactylis glomerata*, *Trifolium pratense*, and *Trifolium repens*. Nitrogen (N) fertilisation rates were 50, 150, and 450 kg N ha^{-1} yr^{-1} (N50, N150, N450). Ten functions were measured representing forage production, forage quality, and N cycling, all being related to either productivity or environmental footprint. Multifunctionality was analysed by a novel approach using the mean log response ratio across functions (Suter *et al*., 2021).

Over three experimental years, mixture effects benefited all forage production and N cycling functions, while sustaining high forage quality. Compared to monocultures at N150, the four-species equi-proportional mixture had 61% more biomass yield, 68% higher temporal stability, 81% less weed biomass, 96% more symbiotic N_2 fixation, 46% higher N efficiency, and 87% less NO_3 in soil solution (each at least $P \leq 0.05$). Thus, mixture effects did not provoke any trade-off among the analysed functions and resulted mainly from beneficial grass-legume interactions. High N fertilisation rates generally diminished mixture benefits. Multifunctionality of four-species mixtures was considerably enhanced, and mixture overall performance was up to 1.9 (N50), 1.8 (N150), and 1.6 times (N450) higher than in averaged monocultures. Notably, multifunctionality of four-species mixtures at N50 was at least as high as in grass monocultures at N450.

We conclude that sown grass-legume mixtures combining few complementary species at low to moderate N fertilisation sustain high multifunctionality and are a ‘ready-to-use’ option for a sustainable agriculture.

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Intercropping heritage and modern wheat varieties with grain legumes

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ABSTRACT

Intercropping wheat and grain legumes could be a possible strategy to increase sustainability of agricultural systems in the Mediterranean Region (Bedoussac *et al*., 2015; Brooker *at al*., 2015). Recently, much attention has been addressed to the cultivation of heritage varieties of wheat as pure crops. Moreover, intercropping wheat and legume crops has been widely suggested for modern varieties due to its positive effects on Land Equivalent Ratio, quality traits of the cereal and ability to reduce weeds compared to grain legume pure crops. Results of two field trials, respectively realized in 2017 and 2019 among the activities of the DIVERSify H2020 project, will be presented.

The 2017 trial involved one durum wheat heritage variety “Cappelli” and one Italian landrace “Solina” of bread wheat, both intercropped (mixed cropping) with one grasspea (*Lathyrus sativus*) landrace previously collected in central Italy. Five combinations of cereal-legume mixed crops were evaluated together with sole wheat and grasspea crops in a Randomized Complete Block design. Results showed for both wheat-grasspea combinations interesting values of LER, together with a significant increase of grain protein content without nitrogen fertilization. The efficient competition of the crops against weeds due to the taller height of wheat and the vegetative development of grasspea suggest this mixed crop combination for organic agricultural systems. In 2019–20 growing season the trial will be repeated and preliminary pre-harvest results will also be presented.

The 2019 trial involved 12 modern bread wheat varieties and 3 fababean varieties evaluated as pure and mixed crops (one mixed crop combination: wheat and fababean at 50% and 65% of the sole crop seed density at sowing). Preliminary results suggest a different performance of each wheat variety with the three fababean varieties in mixed cropping, fababean varieties showing a different competitive ability for wheat. It should be noted that weather conditions, especially in May 2019, favoured the development of fababean compared to bread wheat but with differences among the three varieties. Overall, the 2019 results showed that including different fababean varieties could be a good approach to select wheat genotypes more adapted to intercropping.

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Evaluation of the effect of grain legumes compared to wheat and oilseed rape on the soil biological functioning: Study of a bio-indicator, the soil nematofauna

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ABSTRACT

In the current French arable cropping systems mainly based on cereals and oilseed rape, grain legume crops provide both a botanic diversification and nitrogen supply, thanks to their ability to fix atmospheric N_2. The effects of legume crops on soil biological activity were evaluated by the analysis of the soil nematofauna in a trial conducted by Terre Inovia on two locations to address the comparative characterisation of some services provided by grain legume crop to the following wheat or rape (or intercropped wheat).

Legume crops (faba bean and pea) led to higher soil biological activity than rape and wheat in the two locations (Levroux and Grignon; France). Bacterial and fungal feeding nematodes tended to be more abundant under legumes than under wheat and rape, indicating an higher microbial activity under legume crops. No significant difference was found between legume/wheat/rape for the two other trophic groups of nematodes: plant feeders and predators. Results were very similar between the two locations which indicates a high robustness of the trends. These results, linked to the presence of legumes in the system compared to non-leguminous plants, reflect increased nutrient availability and increased primary decomposer activity, comparable to the effects measured following mineral fertilization, in particular nitrogen fertilization.

Session 8: Yield increases and Benefits

Managing faba bean to reduce the yield gap: A synthesis from the Legume Gap project

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ABSTRACT

The potential of legumes to simultaneously contribute to several production, environmental, and nutritional objectives, is well known by science and policy. Legumes contribute to increased European protein self-sufficiency, diversification of cropping systems and farm businesses, reduction in fertilizer and pesticide use and greenhouse gas (GHG) emissions, enhancement of sustainable diets, and prevention of land degradation and biodiversity loss. Despite the widely recognized benefits of legumes, the European hectarage declined steadily since 1960 and is now growing only slowly. Grain legume yields are characterized by significantly higher variability than winter cereals. There is also evidence of a trend towards declining yields.

The LegumeGap project identifies, quantifies, and proposes approaches for closing several types of “gaps” in legume production. There are widely recognized differences (“yield gaps”) between potential, exploitable, and achieved grain yields and protein yields, where potential yield is that reached in non-limiting conditions, exploitable yield that reached with selected realistic limitations such as rainfall, and achieved yield is that harvested by regional farmers with generally used practices (van Ittersum et al. 2013). Grain legumes, like other crops, are subject to a range of biotic and abiotic stresses that contribute to the yield gap. In this paper we address the impact of management on alleviating these stresses, focusing particularly on the important practices of irrigation, inoculation and tillage.

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Bridging the Gap – the Bean Yield Enhancement Network

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ABSTRACT

The Bean Yield Enhancement Network (YEN) was initiated in 2019 by ADAS and PGRO with the support of industry sponsors; it aims to enhance farm bean yields through promoting crop monitoring, sampling, and sharing of data hence learning about key yield-affecting factors.

For each crop entered, a localised biophysical yield potential is estimated from the light and water resources available at each site in each season, using local daily weather data combined with a soil description for the field. The model is set to combine the best levels of resource capture and conversion observed in research on this species and is under constant review. Thus, it assumes:

- Green area indices (GAI) throughout the season and light extinction coefficients that give around 55% and 65% capture of annual incident total solar radiation by spring and winter crops respectively,
- A radiation use efficiency (RUE) of 1.0 tonne TJ^{-1} and water use efficiency of 4 g l^{-1} (or 24 mm t ha^{-1}) – less than those for cereals (1.4 t TJ^{-1} and 5.5 g l^{-1}) to account for the costs of N fixation,
- A maximum rooting depth of 1.0 m, with roots growing by 1 cm per day, and
- A maximum harvest index (HI) of 60%.

Resulting potential seed yields ranged between 12 and 15 t ha ha^{-1} in 2019 and between 8 and 16 t ha^{-1} in 2020.

Yields are recorded and crop samples are analysed for harvest index, height, nutrient content, and seed quality, and data are collated on agronomic and environmental conditions. To date the dataset contains 52 yields, 20 from the 2019 season and 32 from the 2020 season. There are 15 winter bean yields and 37 spring bean yields. In 2019 the average potential yield was 12.8 t/ha, the average field yield was 5.5 t ha^{-1} (5.8 t ha^{-1} for winter and 5.4 t ha^{-1} for spring crops) so the average percentage of potential achieved was 44%. In 2020 the average potential yield was 13.7 t ha^{-1} for winter crops and 11.7 t ha^{-1} for spring crops. The average field yield was 4.3 t ha^{-1} (3.8 t ha^{-1} for winter and 4.5 t ha^{-1} for spring crops). The average percentage of potential yield achieved was 27% for winter and 38% for spring varieties. Preliminary analysis of the data showed positive associations between yield and leaf potassium concentration at flowering, seeds m^2, thousand seed weight, biomass per shoot, and harvest index. Yield was not associated with growing conditions or husbandry.

In conclusion, British bean growers are achieving around 40% of the crop's potential, which suggests that much work is needed to enhance yields on farm. The Bean YEN continues in 2021 with the aim of having sufficient entries to identify

metrics (whether of crop, agronomy or soil) that associate with yield. YENs work to the hypothesis that fastest progress in crop performance will depend on quantifying, collating and understanding as much data as possible that describe the likely influential factors under farming conditions.

Impact of climate on grain legume yield stability

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ABSTRACT

The resilience of agricultural systems is key in adapting to climate change. Yield stability is also an important goal in agricultural production, especially in the face of increased climate variability. Yield stability is particularly relevant in Europe-grown grain legumes. Their yields tend to be more variable than yields of some other crops and could be the first indicators of a general decrease in yield stability over the last decades. There is insufficient knowledge about the relationship between yield stability of different grain legume species in different environments and changes in climate variability and extreme weather events. Such analyses and a fundamental understanding of the processes involved are needed to inform agronomy and plant breeding efforts to adapt grain legume cropping systems to climate change. We quantified changes in temporal yield stability using an adjusted coefficient of variation (aCV) and the influence of climate for pea and faba bean in three long-term experiments (LTE) in Borgeby (Sweden, 1960–2015), Berlin-Dahlem (Germany, 1953–2008) and Halle (Germany, 1950–2012). The objectives were to, (i) quantify the relationship between climate variability and yield stability for grain legumes under different bio-physical conditions, and (ii) quantify the effect of precipitation and temperature on yield stability. The results show that during the periods of the experiments, temperature increased significantly in Borgeby and Berlin-Dahlem, by 1.7°C and 1.6°C, respectively, and did not change significantly in Halle. There was no trend in the annual precipitation across the sites. While yield instability of grain legumes increased significantly in Borgeby and Berlin-Dahlem this was not the case in Halle. In Borgeby and Berlin-Dahlem, there was a positive relationship between temperature (annual and April–July) and yield stability, and a positive relationship between temperature variability (% CV) and yield stability. Annual precipitation did not affect yield stability but precipitation during specific periods did. In Halle, precipitation between April and July was significantly and negatively correlated with yield stability of pea. We conclude that the analysis of yield data from LTEs enables detecting general trends in yield stability changes over the last decades. In the two sites with a significant increase in temperature (Borgeby and Berlin-Dahlem) there was a strong positive association between climate variability and yield stability for grain legumes

which was not observed in Halle that was characterized by only minor changes in temperature. This knowledge supports efforts in plant breeding and adapting the agronomic management of grain legumes to support the protein transition in Europe.

Effects of high CO_2 on the growth and stress tolerance of soybean

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ABSTRACT

High atmospheric CO_2 concentrations (eCO_2) have positive effects on the productivity and yield of legumes, such as soybean (Ainsworth & Long, 2021). However, eCO_2 also influences shoot architecture and susceptibility to insect pests via mechanisms that remain poorly defined. We therefore studied the effects of (eCO_2) on shoot parameters and the fecundity of pea aphid in wild type peas and mutants defective in either strigolactone (SL) synthesis or signalling. Growth under eCO_2 significantly increased the height and the branching of the wild type shoots. The effects of eCO_2 was less evident in the SL-deficient mutants, the effect on height being significant only in the *rms3-1* mutant and the effect on branching being only significant in the *rms1-2* mutant. While growth under eCO_2 significantly increased the dry weight and sucrose and starch contents of all the lines, the shoot fresh weight/dry weight ratios were decreased by eCO_2 only in the wild type. The mutant shoots had significantly higher fresh weight/dry weight ratios than the wild type under both growth conditions. Aphid fecundity increased in the SL mutants under both ambient and eCO_2 conditions. SL-dependent regulation of aphid fecundity may be related to effects on shoot gibberellic acid (GA_3) levels, which were decreased in the SL mutants. Taken together, these studies provide evidence that SLs are important regulators of shoot acclimation responses to eCO_2 and phloem-feeding insects.

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In vitro and *In vivo* screening through seed defense biopriming with PGPR, *Trichoderma* and Rhizobia for enhancing green pod quality, growth, production and health of *Phaseolus vulgaris* L. in mid-hill zone of Himachal Pradesh, India

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Abstract

Seed defense biopriming is a budding technology which combines the seed priming with biologically active bioagents. There are many crucial mechanisms are involved in defense biopriming like induced systemic resistance and systemic acquired resistance, which enhanced the overall growth of plant, yield, quality of pods and reduced incidence of disease causing agents. In 2017 the *in vitro* investigation of nine indigenous bioagents including, three plant growth promoting rhizobacteria, three rhizobium strains and three *Trichoderma* spp. were standardize for time and duration. We found that, seed biopriming of *Phaseolus vulgaris* L. with PGPR-1 @ 10^9 cfu ml^{-1} for 6 h, *Rhizobium* strain- B1 @ 10^9 cfu ml^{-1} for 8 h and *T. viride* @ 10^7 cfu ml^{-1} for 6 h were best for seed germination and health under *in vitro* condition. The selected bioagents and their consortium were used for seed biopriming under *in vivo* condition to observe growth, green pod yield and disease incidence in *kharif* 2017–18. In both the years, plant height (38.49 cm), days to 50% flowering (30.17), No. of green pod per plant (27.50), average green pod weight (5.36 g), pod length (15.55 cm), pod width (1.38), pod size (21.66), days to first picking (40.33), green pod yield per plant (130.40 g), green pod yield per plot (2721.54 g), green pod yield per hectare (146.64 q) and quality of green pods were found best when seed was bioprimed with T_4 *i.e* combination of PGPR-1 + Rhizobium strain B_1 followed by T_7, consortium of PGPR-1 + *Rhizobium* strain B1 + *Trichoderma viride.* Seed defense biopriming with these consortiums of biagents were found superior over hydropriming, treated and untreated control. However, the biopriming of seed reduce disease incidence, increase nodule formation and yield in *Phaseolus vulgaris L.*

Key words: Seed, Biopriming, Defense, Consortium, Yield, Quality, Health

Forage legumes for future dry climates: Relative yield totals under drought conditions

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Introduction

Projections for future climates show changes in precipitation and temperature patterns, which will affect the forage biomass production, quality and sward botanical composition of rainfed grasslands. Under sufficient water provision, *T. repens* mostly outperforms alternative legume species in grass-clover swards. However, *T. repens* is known to be susceptible to drought (Knowles *et al*., 2003). In an earlier study under controlled conditions (roofed, open-sided greenhouse), we have shown that under drought conditions pure stands of minor forage legumes can have lower relative yield losses than white clover (Komainda *et al*., 2019). However, there is still a debate about whether experiments under controlled conditions are useful to assess drought effects and also about whether minor forage legumes are competitive in grass-clover production. The present study tests the hypothesis that i) experiments under controlled conditions lead to the same conclusion when assessing species performance and ii) that under drought conditions the Relative yield total (RYT) of mixtures with minor legumes is higher than in swards with white clover.

Material and Methods

Six legume species (*Lotus corniculatus, Lotus uliginosus, Medicago falcata, Medicago lupulina, Trifolium repens, Onobrychis viciifolia*) were established in binary mixtures with perennial ryegrass (*Lolium perenne*) and as pure stands in a field experiment and also in a greenhouse trial in a completely randomized experimental setup with four replicates each and no additional fertilization. The field experiment was carried out under subatlantic climate conditions in northwest Germany on a sandy soil with a field capacity of 24 mm dm^{-1} near Oldenburg over three growing seasons in a three-cut defoliation system. The greenhouse trial was conducted over 1.5 years with three drought periods in total. The factor drought stress was introduced using rainout shelters in the field over *c.* 35 days during two regrowth periods per year. Accordingly, in the greenhouse experiment, drought treatments were stopped from being watered until first signs of wilting occurred (Komainda *et al*., 2019). In both experiments, control plots were subjected to rain or standard watering. The swards were harvested after each drought period by manual cutting and the legume and grass dry matter yield was determined after drying (48 h, 60°C) and weighing. For the purpose of the present study, treatment-specific (drought stress × legume species) biomass yields averaged over the whole experimental duration in the field and greenhouse were calculated. The mixture yield of a component species expressed as a portion of its yields as a pure stand from the same replacement series is the relative yield of the crop and the sum of relative yields of each component is called relative yield total (RYT) (De Wit *et al*., 1966). A linear-mixed effects model was used with the fixed factors experiment (greenhouse, field), species (six levels), stress level (control vs. drought) and their interactions. The replicate served as random factor and posthoc comparisons of means were performed using Tukey's test.

Results

There was a significant interaction of sward × experiment (F=10.3, *P*<0.001). Comparisons of means showed that the RYT between swards differed within each experimental setup which partly contradicts our first hypothesis. While white clover swards had the greatest RYT in both, the field and the greenhouse, the minor legume mixtures mixed with *Lolium perenne* differed in the field, but only marginally in the greenhouse (Fig. 1). In the field mixtures of *Lotus corniculatus* and also *Lotus uliginosus* performed well (Fig. 1). In the latter case grass dominated the mixture and was responsible for the reaction. The factor stress had a significant effect (F=12.8, *P*<0.001) on RYT, but there was no interaction with the factors experiment or sward. The RYT in the stress and control treatments differed significantly (*P*<0.001) and were on average 1.29 and 1.47, respectively. The second hypothesis that under drought conditions the RYT of minor legume species in mixture with *Lolium perenne* might be higher than the respective mixture of white clover needs to be fully rejected.

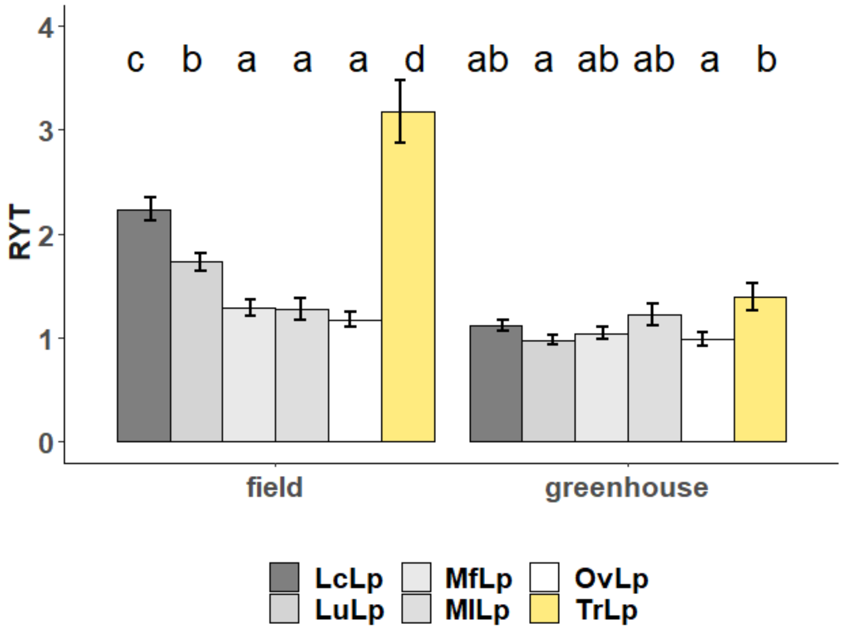

Fig. 1. Relative yield totals (estimated model means ± SE) of different mixture swards in the field and greenhouse experiment. Lc: *Lotus corniculatus*, Lp: *Lolium perenne*, Mf: *Medicago falcata*, Ov: *Onobrychis viciifolia*, Lu: *Lotus uliginosus*, Ml: *Medicago lupulina*, Tr: *Trifolium repens*. Columns with different lowercase letters per experiment (field, greenhouse) differ from each other (*P*<0.05).

Conclusion

Lotus corniculatus (birdsfoot trefoil) is a promising forage legume for sandy soils, although the RYT was lower than with white clover-based production.

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Secondary agriculture perspectives zinc and iron bio-fortification in chickpea

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ABSTRACT

Chickpea is an important crop in India with 71% of world area. It is important source of protein and mineral nutrients for vegetarian population of India. Zinc and Iron deficiency is prevailing in most of the soils and cause reduction in yield due to impairment in fertilization, poor development of seed and chlorosis etc. Apart from this, zinc and iron deficiency in soil leads to lower content of this micronutrient in seeds and cause physical and mental health problems to human beings. In this experiment two genotypes of chickpea (JG-11 and GBM-2) were main plots and sub plots were six Zn and Fe management practices (control, 0.5% $ZnSO_4$ foliar spray alone, 0.1% $FeSO_4$ foliar spray alone, 0.5% $ZnSO_4$ + 0.1% $FeSO_4$ foliar spray, application to soil with 20 kg $ZnSO_4$ ha^{-1} and seed treatment @2g kg $seed^{-1}$). Foliar sprays were at both flowering and pod initiation stages. Experiment was laid out in split plot with three replications. Foliar application of Zn @ 0.5% along with Fe @ 0.1% (T_4) proved better method of application of Zn and Fe compared to soil application and seed treatment of Zn and Fe. Yield increase was 20.2% and 21.5% higher in T4 over control respectively in 2016 and 2017. Both the genotypes accumulated 35 to 42 mg Zn and 27 to 30 mg of Fe kg^{-1} of seed for different treatments. However, there was not much difference with regards to uptake pattern of Zn and Fe in seed by genotypes. There was marked difference in Zn and Fe accumulation due to application methods of Zn and Fe compared to non application of these micronutrients. Application of Zn @ 0.5% along with Fe @0.1% recorded 16.8% higher Zn accumulation in seed over non application of micronutrients. Seed yield per plot, no of pods per plant, dry weight, 100 seed weight and agronomic use efficiency of Zn also showed increasing trend in this treatment compared to control treatment without Zn and Fe.